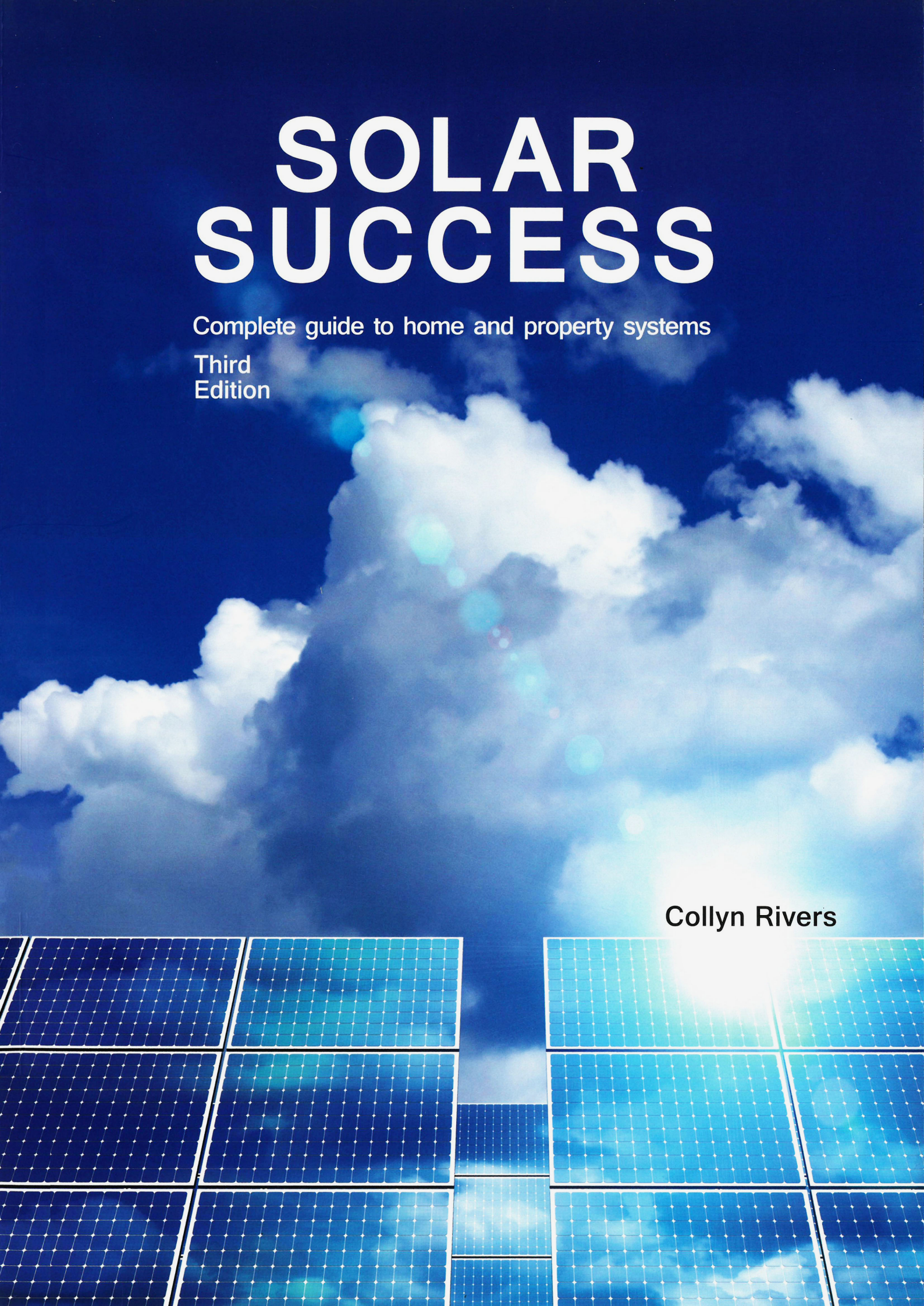
# SOLAR SUCCESS

Complete guide to home and property systems

Third Edition

Collyn Rivers



# Solar Success

## the complete guide to home & property systems

By Collyn Rivers

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# Preface

Since this book was first published in 2008, Denmark has become by far the world leader in the usage of solar and wind power. The electricity it generates is not only 100% solar and wind powered, but 30% more is exported as well. Iceland too is virtually energy self-sufficient (using mainly geo-thermal).

Australia's solar take up is now high in rural areas. Properties that had primarily relied on diesel generated power are increasingly installing solar to provide power throughout much of the year. Our major increase in solar usage, however, is grid-connect systems in urban areas. Australia now has the highest percentage of such installations (pro rata population) in the world - about 1.4 million installations by 2015. Over 40% of all owner-occupied houses in Queensland and South Australia now have solar. Most local systems, however, are of 5 kW and less, whereas over 85% of those in Germany exceed 10 kW.

Except for Queensland where usage rose by just under 10%, Australia's *average* electricity usage increased considerably from 2000, peaked between 2006 and 2008, then, partially due to the increasing efficiency of electrical appliances and lighting (plus a minor but growing effect from solar) has fallen to year 2000 levels. But whilst average demand is falling, the demand during peak periods is falling at a lower rate, and this is a major problem for electricity generators.

Most grid power is supplied by a small number of huge 'base-line' generators that are not able to increase or reduce their output over short periods (the technology precludes a short term 'volume control'). Solar feed-in energy assists reduced demand but that fed into the grid is mostly between 10 am and 2 pm - when it is least needed. Further, there is also no currently known way of storing electricity on a centralised scale.

Our generating network is now currently larger than it needs to be during off-peak periods, but must have that extra capacity to cope with the peak loading. Meanwhile the electricity generating industry can only retain its return on massive investment by increasing prices. It has done so in Queensland by over 85% (in real terms) since 2007.

Introducing profound problems of monetary inequity, these price increases are paid by all. Non-solar users literally subsidise early grid-connect solar users who, in Queensland and South Australia, have feed-in payments of 44-60 cents per kWh guaranteed until 2028.

## A virtual transformation

In what is in effect a virtual transformation of the way we buy and use electricity, major changes in grid-connect solar usage and electricity tariff structures are to be introduced progressively between 2017 and 2022. These changes, outlined in pages 58-61 of this book, will affect *all* users (solar or non-solar), but particularly those with large scale grid-connect systems who are not receiving high feed-in tariffs.

The most likely initial changes to the structure of electricity pricing are outlined on page 59. The method is expected to be much the same from state to state. It is likely to made known officially in mid 2016, and to come into effect progressively from 2017-2022.

Reader feedback shows that many *Solar Success* readers have or are considering stand-alone systems. Here, the proposed changes are likely to indirectly benefit those with no realistic access to grid power. There will be major pressure on grid-connect users generally (i.e. not just solar grid-connect owners) to install battery inverter systems (pages 58-61). This will hugely boost demand and hopefully result in a major fall in battery prices. This alone is expected to result in a major increase in the number of users using stand-alone solar systems in rural areas. It *may* also do so in those semi-rural and semi-urban areas where back-up generators are acceptable. In the author's current opinion, however, grid-connect power would need to exceed $1.30 per kWh for this to be begin to be economically worthwhile.

Updates of matters relating to the above will be posted from time to time on our related website: successfulsolarbooks.com

# General

Any book relating to solar and/or electrics written for a general readership runs into an immediate problem with the term 'low voltage.' To many non-technical people, that term tends to be associated with 12 volts or so - a voltage that is generally harmless. But to electricity regulators, electrical engineers and technically minded lawyers, Low voltage (i.e, with that capital letter 'L') legally defines something quite different.

The actual definitions are given on page 98, but briefly, that which most people tend to call 'low voltage' legally includes that output which comes out of wall outlet sockets in homes and businesses, and also the 415 volts three-phase systems used for big ovens and many industrial loads.

The output from those sockets is known by various names. Americans have over 20 different terms for it. The British and some Australians call it mains power. Others misleadingly call it grid power. Sailors call it shore power. Unless noted otherwise, this book uses '230 volts' or 'mains voltage' to mean any or all of the above. Legally it is now defined as 230 volts +6%/-10% (in Australia and New Zealand) but in practice it is often close to 240 volts.

In Australia and New Zealand, voltage that is less than 50 volts ac or 120 volts dc is known legally as Extra-low voltage. There are also two further versions (that are below that voltage). Only in the USA does it vaguely imply what most people think it implies: there, the so-called low (distribution system) voltage is 0-49 volts ac or dc.

To avoid confusion, except where necessary for legal and technical reasons, this book refers to 110-230 volts as that (and/or mains power).

A further but lesser issue relates to the usage of the term solar panel. To the solar industry, however, that which many call a 'solar panel' is a solar module. A number of such interconnected solar modules is a solar panel. A number of interconnected solar panels is a solar array.

As that terminology is used in makers' specifications and installation manuals *Solar Success* has little choice but to use the term solar 'module' too.

## Credits

Many people assisted in the production of this book. Firstly, I thank my wife Maarit, for her patience during my intellectual absence during its writing.

Especial thanks also to (the late) Barry Powell, and Lawrie Beales for their totally invaluable critique and technical proofing of the original drafts, and my daughter Fiona Rivers for final proof-reading.

I also thank the Clean Energy Council for providing assistance, and the Australian Bureau of Meteorology for the base solar data from which our maps on page 54 were prepared. I also acknowledge the Grattan Institute for invaluable background information relating to future solar and electrical industry changes.

# Solar Reality – an overview

The sun is not an infinite resource but circa 2015 the world's energy needs could be supplied by 0.007% of that available yearly. Around midday, countries at similar latitudes as Australia, New Zealand and South Africa have 800 to 1000 watts of solar energy falling on each flat square metre. Currently affordable solar modules are 14% to 20.5% efficient: solar reality is thus about 120-140 watts per square metre.

To use that energy at night we store it in a battery and draw on it later, or use the electricity grid as a 'virtual battery', drawing power when we need it, and selling it back when we don't. Initially, that rebated exceeded that paid, but most users now receive a fraction of that charged by electricity suppliers.

The amount of sun available (irradiation) depends on locality, cloud cover and time of year. The most you are likely to harvest in a full day is seven times that available for an hour around noon. Three to five times is typical in most temperate areas much of the year and two to three and a half times in mid-winter.

Solar irradiation is quantified much as is rainfall, i.e. that which falls in a day, rather than minute by minute. By recording solar input over time, peaks and dips average out as the sun (apparently) sweeps the sky, and is obscured at times by cloud. Irradiation maps show the result in so-called Peak Sun Hours (PSH) of which each is much the same as one hour of strong 'noon-time' sun.

Maps on page 54 show averages for Australia's mid-winter and mid-summer. The change from mid-winter to mid-summer is generally smooth, but some places (such as parts of New Zealand's north island) have faster changes due to seasonal cloud cover. To ascertain the amount of electricity one can realistically expect each day, multiply the relevant Peak Sun Hours (PSH) by 70% of the marketed wattage of that module (why 70% is explained later). Such data for other parts of the world is obtainable from meteorological offices.

Home and business solar begins to be worthwhile where there's at least 2 PSH a day: e.g. in a Tasmanian/ New Zealand/British mid-winter. Solar really comes into its own from 3.5 PSH onwards. In mid-summer Brisbane, there is about 6.5 PSH. A 200 watt solar module will thus produce about 140 watts times 6.5 hours, or 910 watt hours/day – often abbreviated as 910 Wh/day.

*This group of houses (60 in all) in Frieburg, Germany, produces 6300 kWh/year: more than three times that each uses. Frieburg is a virtually all-solar town, most public and commercial buildings too are solar powered. Pic: Frieburg.*

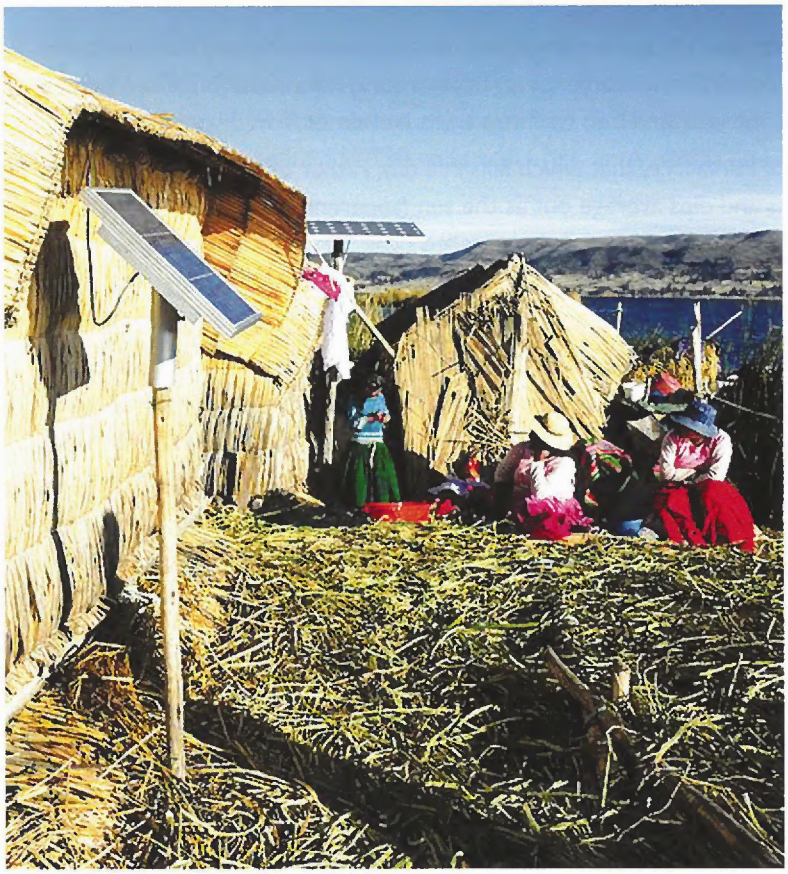
## What runs/what doesn't

Solar works best if you've firstly reduced consumption to the minimum. This requires minor changes – but not necessarily inconvenience.

Water heating is best done by conventional solar water heaters, cooking by gas, and space heating by passive solar and adequate heat insulation. Most everything else can be economically powered from solar and a great deal of money is saved by using efficient lights and appliances.

Most domestic fridges guzzle energy. Some use half the day's total energy. As pages 13-14 show, this can be halved by using today's more efficient examples, and installing them properly.

Many water pumps (particularly swimming pool pumps) are inefficient - they guzzle energy. Major savings can be made here by using one of the variable speed pumps described on page 27. Where water is pumped within a property, consider the pressure tank system described on pages 27-28.



*Small-scale solar - Lake Titticaca (Peru). Pic: Photocoen.*

Efficient washing machines can be run from solar power and solar hot water, but cold-water washing products do a good job and are kinder on clothes. Front loaders use less power and less water.

Dishwashers normally use energy in heating cold water. Some accept heated water but this is not energy efficient unless the hot water feed is well insulated.

Efficient lighting saves energy, as does turning off lights that are not needed. Incandescent globes are now banned from sale in many countries. Halogen globes are likely to be eventually as well.

Fluorescents use about 25% of the energy drawn (for the same light) by incandescents. LEDs (Light Emitting Diodes) use even less.

There are fewer energy usage problems with post 2014 medium-sized TVs, but regardless of their technology the major draw (i.e. of the screen) is always proportional to the square of its size.

Laptop computers draw much less energy than do desktop computers, but as teenagers see them as uncool this is a situation a parent is unlikely to win.

Air conditioning is feasible with large solar systems, but first improve climatic comfort via natural and passive methods. Despite vendor claims to the contrary, evaporative coolers are not effective in over 30% humidity.

Solar powered irrigation is feasible, as are domestic swimming pools by using techniques shown in this book.

## Stand-alone systems

Two main types of domestic and property solar systems are in current use. 'Stand-alone' systems are used mainly where grid power is unavailable but are beginning to be considered instead of grid-connect more generally as electricity prices increase and battery prices fall.

The most basic is a solar water pump that fills a tank or dam when there's sufficient sunlight. The pumping volume varies with the sun's intensity. A so-called 'maximiser' can boost pumping by increasing effective output during early mornings and late afternoons.

Most systems are more complex. Energy is generally needed at all times and to do this it is stored in batteries and drawn upon when required. A basic system for a cabin or caravan needs only a solar module or two, a solar regulator, a battery and 12 volt lights and appliances. Millions of cheap, simple and reliable systems like this are transforming life in India, China and South America.

For larger cabins and general household or property use, it is more practical to use efficient 230 volt lights and appliances via an inverter, (an inverter changes battery voltage to ac mains voltage).

Solar only systems work best where there is little difference between summer and winter sun, but where there *is* a big difference, as in Tasmania, New Zealand, parts of the USA and the UK, it makes economic sense to use solar energy for lighting, refrigeration, kitchen appliances and TV, etc. most of the year, and generator back-up during mid-winter and extended cloud cover. The generator also runs rare heavy loads such as big arc welders, air compressors and extended water pumping. Small scale affordable fuel cell systems (pages 48-49) are likely eventually to replace conventional generators.

For more general larger-scale use, consider running routine loads from solar (with battery capacity back-up for two to three days). A small diesel-powered generator supplements battery charge when required. The balance between solar and battery capacity, and other generated power, constantly changes as solar capacity becomes increasingly affordable, battery and fuel prices rise, and rebates fall.

## Grid-connect

Where mains electricity is readily available, 'grid-connect' to some extent enables its use as a virtual battery. When more energy is needed than solar generated, it is drawn from the grid. When there is more solar energy than needed, (as is common during the day) the surplus is fed into the grid and paid for by the electricity supplier.

A drawback of basic grid-connect is that if the grid supply fails, your solar power too is usually automatically disconnected from your own premises. Such outages, at least for lighting and computer systems, etc. can be avoided by including battery back-up and a suitable inverter (pages 58-61).

As explained in pages 58-61, the system as originally conceived has proved to have major flaws. Resolving the issues requires major changes that will affect both existing and future users of grid-connect systems - and electricity users generally. The changes are not yet finalised but are expected to come into effect in 2017. Further updates re this will be posted on our associated website: successfulsolarbooks.com

## What solar modules really produce

No typical commercial solar module in real-life usage produces that which vendors appear to claim. The output claimed can only be achieved briefly in freak conditions, or replicated in a testing laboratory. Solar modules used in stand-alone systems actually produce 70%-80% and grid-connect systems 85%-90% of that

*A village in the tribal area of Melghat, Chikhaldara, India. The Indian government assists solar installation for outside lighting, and for each home. Pic: taken in 2007. Bspujari © dreamstimes.com.*

apparently claimed (a '1.5 kW' grid-connect system's probable maximum output is 1.25 kW). This *is* revealed by the solar industry (see page 35) - but in terms that mostly only electrical engineers understand. Despite this buyers are charged and rebates paid for the inflated claims.

## Power factor

Many devices that run from alternating current cause the peaks of the constantly alternating voltage and current to lag or lead each other. The effect is like rowers pulling out of synchronisation: the same energy is exerted, but to less effect. Some current is constantly 'borrowed and returned' to and from the supply - thus filling in the 'gaps'. This effect, called power factor, does not increase the electricity *consumed,* but that 'borrowed' must be made available by the supply. Adverse power factor necessitates electricity networks to be oversized accordingly. With solar it necessitates inverters and generators to be (20%-30%) larger than might be expected, but not battery banks (as that extra energy made available is not consumed). In many cases, adverse power factor can be partially corrected. Electricians know how to do it, but financially this is only worth doing for major equipment.

## Solar access

In Australia at least, there is currently no general legal right to ongoing solar access. Unless there is prior agreement there is little you can do if a shire or council approves a structure that blocks your system's previous access to sun.

This may change following a 2013 ruling by the Victorian Civil and Administrative Tribunal that refused to accept a proposal for two double-storey dwellings that would have partially overshadowed solar modules on an existing adjoining home. Such overshadowing would have slashed solar input by 50%-70% between 9 am and until after midday (at the equinox). The tribunal warned that higher density urban living, especially near transport hubs, must lead to ongoing fights between developers and solar users 'to introduce clearer guidelines for determining what is an acceptable level of solar module over-shadowing.'

Intending urban users are advised to consult their local council if there is any possibility that nearby development could restrict future solar access.

## Service importance

Whilst efficiency is important, so is repairing stuff that goes wrong. If you live in a major city or large town there are rarely problems, but it is a different matter altogether in less populated areas. The closest repair shop may be hundreds of kilometres away. Before purchasing Check *Choice* magazine's reliability rating for the appliances in mind (or at least of their makers).

*Pic: Victoria's* Herald Sun.

# Lighting

Lighting consumes a fair bit of energy – not just because people have a lot of it, but also because so many lights are left on when not needed. Also not helping is the myth that energy is not saved by turning off lights.

Incandescent globes are essentially small glass-enclosed electric fires that also produce small amounts of light. Where air conditioning was used, yet more energy was spent in pumping out their heat. As noted previously, such globes were progressively banned from sale from 2009.

## Halogen globes

*Halogen globes - still used but now being replaced by LEDs. Pic: author.*

Halogen globes are the ultimate development of candles. They are a marginally less primitive form of incandescent globe that produce more light, but by running so hot (700° C), they require precautions against fire. Halogen globes use a technology whose era is all but past. They are no longer recommended except for specialised use.

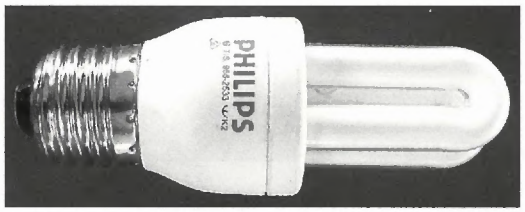
## Fluorescents

Fluorescent tubes have been with us since 1901. In their present form they use only one quarter the energy of an incandescent globe of the same light output. They are cheap and effective but bulky for the light they produce. Some people dislike their harsh white light, but warm white alternatives have long been available. All conventional fluorescent tubes have a slight flicker, but it only irritates some people. Those tubes with a triphosphor coating produce about 15% more light. They are claimed by vendors to last longer.

## Compact fluorescents

Compact fluorescents are as efficient as tube fluorescents but a fraction of their size. Most fit readily into existing fittings. They are available in an ever-increasing range of shapes, light colour and light output. All are flicker-free. Spotlight and insect repelling versions are also available.

A 22 watt compact fluorescent globe is comparable to a 100 watt incandescent.

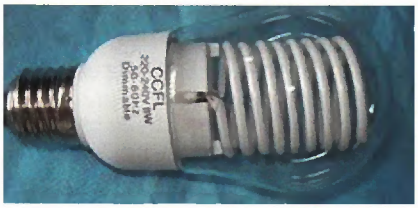



*Twelve watt compact fluorescent produces much the same amount of light as a 50 watt incandescent: Pic: author.*

These globes cost more than incandescents but last longer. A few fail within hours, but most last for years. Test them immediately after buying, so that faulty units can be replaced under warranty without argument.

## Cold cathode

These resemble compact fluorescents, but are 10%-30% more efficient, and dimmable to about 30% of their output. They are of the same size and shape as the earlier incandescent globes and obtainable from about 7-40 watts. Most have a standard Edison screw base. They cost more than than compact fluorescents but last longer.




*Cold cathode globes, great lamps but hard to locate suppliers. Pic: author.*

## Light emitting diodes

Efficient coloured LEDs have been around for many years but, until 2008 or so, white light could only be produced (and then inefficiently) by using a mix of coloured LEDs in one casing. White light and warm white light producing LEDs are now readily available.

Most LEDs produce light in a conical pattern designed to fall where needed, and *only* where needed. Such LEDs are fine inside cupboards, as torches, for reading, for step and night lights, but not for general lighting. Some now produce a 120° cone of light but those for 360° degree illumination are costly and currently little more efficient than compact fluorescents of the same wattage, but their efficiency is constantly improving.

The most common types of LEDs run at a typical 12 volts and have two thin pins that fit into a so-called MR16 base. Some operate from 9-24 volts plus and are driven by a nominally 24 volt supply - handy where existing cable is too light for 12 volt use. Also available are (MR11 base) LEDs that have similar pins but spaced closer together. Popular for home use are the so-called GU 10 types (lower left) that run from 230 volts. There are also 230 volt versions with an Edison screw base.

*Five watt LED -replacement for MR 16 (35 watt) halogen globes. Pic: successfulsolarbooks.com*

*This 7 watt LED runs directly from a 230 volt supply. Pic: author.*

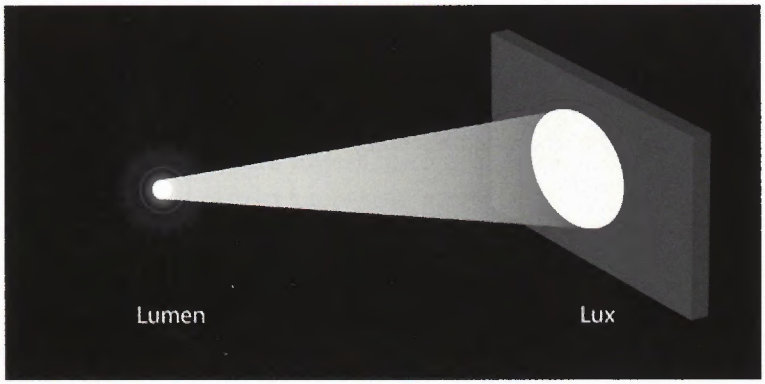
There is massive and ongoing research and constant developments in this field. The US Government noted in 2009 that white LEDs will revolutionise office and domestic lighting. This (2015) has now happened.

## Light colour

White light (4000° to 5000° Kelvin) is that primarily associated with fluorescent tubes. It is a good choice for kitchens and reading lights, but many perceive it as 'cold'. Warm white (2700° to 3100° K) is often preferred for background lighting, bedrooms and outdoor areas.

## Lighting levels

Lighting levels are measured in two main units: lumens, and lux. A lumen is a measure of the total amount of visible light produced by a light source. It is a good indicator of a light source's energy efficiency. Lux is an absolute measure of light falling on a surface - and is what most people are primarily concerned about.




*Pic: Original source unknown*

These two units are interrelated. The light level from a light source of (say) 1000 lumens over 1 square metre is 1000 lux.

Were that same 1000 lumen light source spread over 10 square metres, the average level falls to 100 lux. In other words, lux takes into account the total area over which the light is spread. This difference is not universally understood.

Homes need background levels of 50 to 150 lux. General tasks like reading and writing require about 360 lux. High precision work may need 500 to 600 lux.

A lighting level of (say) 100 lux currently requires about 1.5 watts for each square metre of area to be lit. Using LEDs, a 20 square metre room would thus need about 30 watts (for background lighting).

As LED efficiency constantly improves it is better, however, to assess light output in terms of watts. LEDs are now best assessed by the lumens they produce. This is usually related to their price. A high quality 5 watt LED may thus produce similar or more light output (lumens) than an eBay 'special' of 8-10 watts.

| Light type | Luminous efficacy in lumens/watt (in 2015) |
|---|---|
| Candle | 0.3 |
| Incandescent (including halogen) | 5-25 |
| Fluorescent tube | 50-70 (80 can be achieved by the triphosphor type) |
| Fluorescent globe | 45-60 |
| Metal halide | 60-115 |
| White LED (and warm white) | 40-110 |
| White LED (prototypes) | 200 plus |

*This table shows the efficacy of various sources of light. It shows the relative brightness per watt as perceived by average human eyes.*

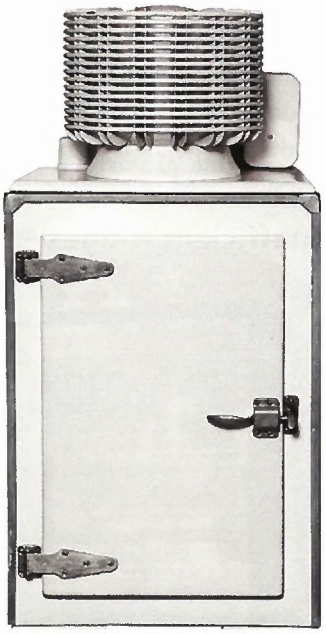
# Fridges & Freezers

Air conditioning, conventional electric heating, and early mega TVs apart, fridges and freezers are the largest energy gobblers in domestic systems. As with air conditioners, they are often perceived as back-to-front heaters that somehow turn electricity into 'cold', but that is not how they work.

A fridge is simply a box that holds stuff you need to cool, and/or keep cool, by having a pump collect heat from its inside (where heat is not wanted) and release it where it does not matter.

It does this by circulating a refrigerant gas (that becomes liquid when compressed) through finned tubes inside the space to be cooled. This gas collects the internal heat that is then dispersed via external finned tubes.

The refrigerant gas is initially compressed. This causes it to become a super-heated vapour that is cooled and condensed until it becomes liquid. It then expands into a very cold part gas/part liquid that is pumped through the fridge's cooling tubes - where it absorbs unwanted heat. The refrigerant continues to flow through the system until it dissipates the unwanted heat via the external cooling fins. Instead of fins some fridges use the side and top outer metal cladding of the fridge to dissipate the heat.



*Antique fridge - the cooling fins are logically at the top. Pic: source unknown.*

Ammonia was originally used as the refrigerant but was dropped because it tended to kill people. It was replaced by Freon - that killed the environment instead. A less destructive product then replaced both.

*Top: pre April 2009 six star rating. Bottom: post April 2010. An extra crown is added for units exceeding six stars.*

There have been major improvements in fridge efficiency in recent years. Huge savings in energy consumption can be made by replacing any fridge made before 2000 or so by a post-2012 high efficiency equivalent.

## Fridge ratings

In Australia, an Energy Rating label helps buyers evaluate the energy efficiency of domestic appliances. Many other countries have similar schemes. For fridges, the star rating indicates a fridge's efficiency compared with others of similar size, plus an indication of yearly energy usage.

The original system allowed for six stars but by 2009 a few exceeded five stars. A 10 star system was thus introduced from 1 April 2010. The revised system also reduced the number of stars awarded for the same energy consumption. As a rough guide, a previously-rated five star fridge is now rated at 3.5 stars. For products that exceed six stars, an additional 'crown' accommodates four extra stars.

| Type | Volume | Star rating (current) | Energy use (kWh/year) |
|---|---|---|---|
| Elcold | 130 | 4 | 177 |
| Elcold | 227 | 3.5 | 273 |
| Haler | 258 | 3.5 | 295 |
| Miele | 304 | 3.5 | 310 |
| Electrolux | 416 | 4 | 318 |
| Miele | 458 | 3.5 | 352 |
| Electrolux | 517 | 4 | 365 |

*The improvements in efficiency stem partially from more effective heat insulation, and partially from improvements in the cooling technology.*

Once you know the size fridge you need the number of stars assists the buying decision, but indicates only the relative efficiencies of fridges of similar size. A 400 litre, three star fridge may thus use less energy than a 500 litre, four star fridge. The 'Energy consumption' panel below the stars shows the actual amount of energy the fridge is likely to use in one year. This is the information that *really* matters.

## Domestic fridges

Generally the bigger the fridge, the more energy it uses, but not proportionally. A 600 litre fridge is likely to draw less than twice the energy of a 300 litre fridge so do not buy two small ones rather than one bigger one. Do not buy one that is smaller than you need as what you may save in electricity you will spend on fuel for shopping more often. Equally though, do not buy a fridge *much* larger than you need.

Many fridges are designed such that they run until the set thermostat temperature is reached, and then cease running until the temperature rises by $1^0$ to $2^0$ C. At that point the cycle recommences. The on/off time ratio depends on various factors including set and ambient temperature, what the fridge is cooling at the time, and how often it is opened and closed. There is, however, an increasing move to fridges that run continuously, varying speed to maintain the preset temperature.

## Inefficient fridges – the cost

*This ETM4200SC 416 litre Electrolux fridge uses only 870 Wh/day. Pic: Electrolux.*

A typical 500 litre 2000-2002 fridge used about 2.5 kWh/day, but as the table on page 13 shows, an efficient 500 litre fridge, in 2015, uses only 365 kWh/year (1.0 kWh/day).

By replacing an old fridge with an efficient one of today, you may draw 1.5 kilowatt/hour a day less.

Apply the same thinking to everything electrical in the house and the savings will surprise.

Yet more energy can be saved by installing a fridge in a manner that reflects how it actually works, in particular by thermally separating it from wherever the heat is pumped. Pages 78-79 show how.

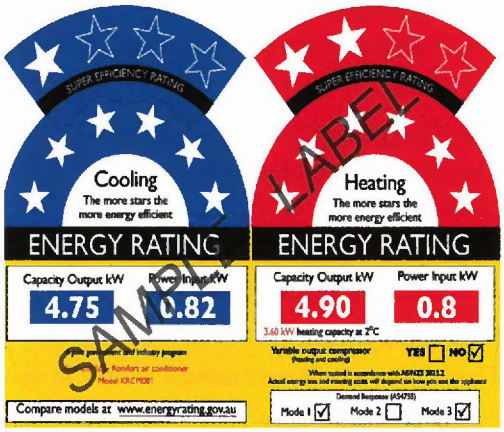
# Air Conditioning

An air conditioner works much like a fridge with its door open. It collects heat from inside a space and releases it outside that space. It is becoming increasingly feasible to run air conditioning not just from grid-connect but also from stand-alone solar. Unless you are 100% certain that you need air conditioning, however, consider the following alternatives:

Daytime areas and bedrooms located in optimum areas enable natural cooling and heating. Light coloured roofs and windows (if local regulations permit) optimises cooling from natural breezes. Minimum interior walls improve air flow. Also assisting is good external shading and increased insulation.

It is particularly necessary to stop unwanted heat entering the cooled area. This is achievable by extra or more efficient insulation in the walls and roof, double or triple glazed windows, doors that close without gaps, and external shading.

The energy efficiency of air conditioners varies over a surprisingly wide range. Reverse cycle units not only cool, but provide extremely efficient heating. The more efficient cost more initially, but the savings on solar capacity required to drive them are huge.




*Post-April 2010 labels: in this case for a reverse cycle unit that provides both heating and cooling.*

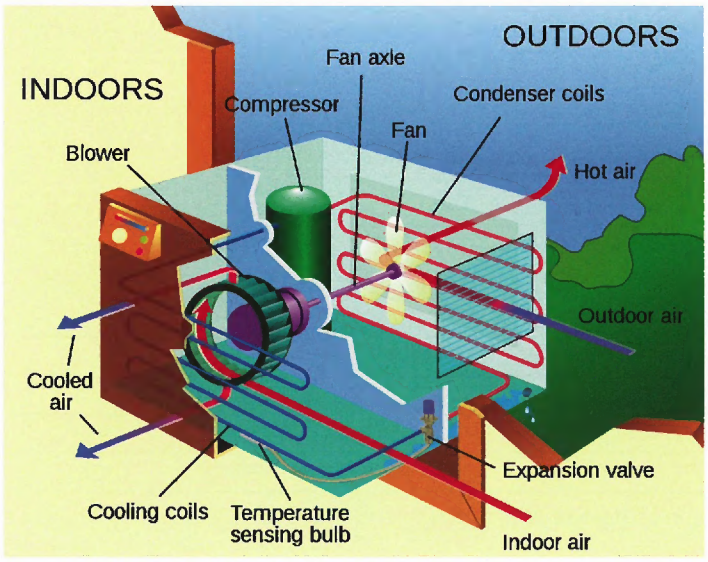
## Star ratings

The original ratings for air conditioners had six stars but by 2009 the most efficient were equivalent to 10-star rating (had there been any such rating back then). The new ratings allow for 10 stars but the old and the new ratings are not directly comparable. The new ones are now based on an annual efficiency calculation that includes 'all non-operational energy consumption'. Daikin's US7 2.5 kW unit is seven star.

Even more so than with fridges, it is *far* cheaper to install efficient new air conditioners than the extra solar and battery capacity needed to drive inefficient older ones. You save money, and gain brand new units.

## Air conditioner types

Apart from reverse cycle units that provide heating as well as cooling, the main types of air conditioner are single unit window/wall systems, and split systems (where the inside bit is remote from the outside bit), and centralised ducted units that cool a complete house.




*How an air conditioner works. Pic: Wikipedia.*

Centralised ducted house systems were in vogue prior to the recognition of global warming but cooling an entire house is now less common.

Single unit systems are ugly and often clumsy, and the early ones are grossly inefficient. Split systems are more efficient and quieter.

## Inverter systems

There are also two main types of operation. As with fridges, many air conditioners cycle on and off to attain an averaged set temperature.

Again as with fridges, there is a move to running continuously at whatever speed is required to maintain the desired temperature. Such air conditioners, known as 'inverter' units, cost more to buy, but a lot less to run.

There is a minor rating/buying trap with inverter units. At their rarely used full load (at which their energy rating is determined) they draw more energy than do conventional units. Most air conditioners, however, are turned down once the desired temperature is reached and, at such part load operation, inverter units are very efficient.

## Reducing consumption

Assuming the area is adequately heat-insulated, etc. the energy drawn by air conditioning relates to its set temperature. Every 1° C increase increases energy draw by 10% or so. Bear this in mind when scaling the system because a few degrees hotter or colder makes a huge difference to running cost.

People may disagree about 'comfortable' temperature because that term depends on the temperature range to which they are accustomed, but given a year or so to adjust, 22°-23° C works well for most.

Many air conditioners have adjustable louvres. For cooling, these should be turned toward the ceiling. Doing so distributes the cooled air more evenly as, by virtue of it being cold, it drops toward the floor. For heating, turning the louvres downward directs the heat towards the floor.

Air filters must be installed correctly and cleaned frequently. If obstructed by dirt, cooling performance falls and energy consumption rises.

## Cooling capacity required

The required capacity substantially depends on how well the cooled area is heat-insulated and the outer walls protected against direct sun. As a guide, 125 watts of cooling capacity per square metre (not power drawn in providing that cooling) suffices for living areas, and 80 watts per square metre for bedrooms. Less is needed if the area has effective insulation and air sealing.

## Reverse cycle

The way some air conditioners work can also be reversed. As well as cooling, they can heat by utilising heat energy pumped in from outside the building. This works better than it might seem because air that feels cold to humans nevertheless contains heat energy. It only ceases having any heat at -273° C (0° K). In practice, reverse cycle operation works best in temperate climates where outside temperatures are above 5° C.

Reverse cycle units have a double panelled label (page 15) that shows their energy usage for both cooling and heating - as is shown also in the table below. It is in this area where major advances are being made. For example, a 20 square metre bedroom needs about 1600 cooling watts. As the table shows, this is readily providable by an efficient unit drawing under 350 watts of electrical energy.

For heating, even the least efficient reverse cycle air conditioners now produce about 2 kW of heat for every 1 kW of electricity drawn. Some now produce over 5 kW - some five times the heat of a typical single bar electric heater.

This type of heating will become particularly practicable with solar grid-connect systems that currently have excess capacity.

Ideally, houses need designing with solar heating and cooling as paramount. If that is done well, many need little or no other form of either. Existing houses are often harder to adapt, but as shown in the following chapter there are also other forms of energy-efficient forms of heating.

| Air conditioners (single split systems | Star rating cooling | Output (kW) | Power drawn (kW) | Star rating heating | Output (kW) | Power drawn (kW) |
|---|---|---|---|---|---|---|
| Daikin US7 FTX225NV1B | 7 | 2.5 | 0.42 | 7 | 3.6 | 0.62 |
| Mitsubishi SRK20ZJX-S | 6 | 2 | 0.35 | 5.5 | 2.5 | 0.45 |
| LG K09AWN -NM11 | 5.5 | 2 | 0.46 | 5.5 | 3.2 | 0.59 |
| Kelvinator | 5 | 2.5 | 0.5 | 5 | 2.6 | 0.52 |
| Samsung AQV09KWAN | 5 | 2.4 | 0.47 | 5 | 3.1 | 0.6 |

*The above are leading air conditioners (in terms of star ratings) as of December 2014. Data by courtesy energyrating@climatechange.gov.au*

# Geothermal Space Heating

Geothermal energy exploits the earth's more or less constant temperature within a few hundred metres of the surface. It was pioneered in Iceland over 100 years ago, when Stefan Jonsson used it to heat his farm. A few other farmers then did likewise.

The first public building so heated (in 1930) was a school in Reykjavik. This was so successful that geothermal heating was used also for the National Hospital and 60 private homes. Now (late 2015) over 90% of Iceland's homes are heated by geothermal energy - mainly from three central power plants, producing over 800 MW.

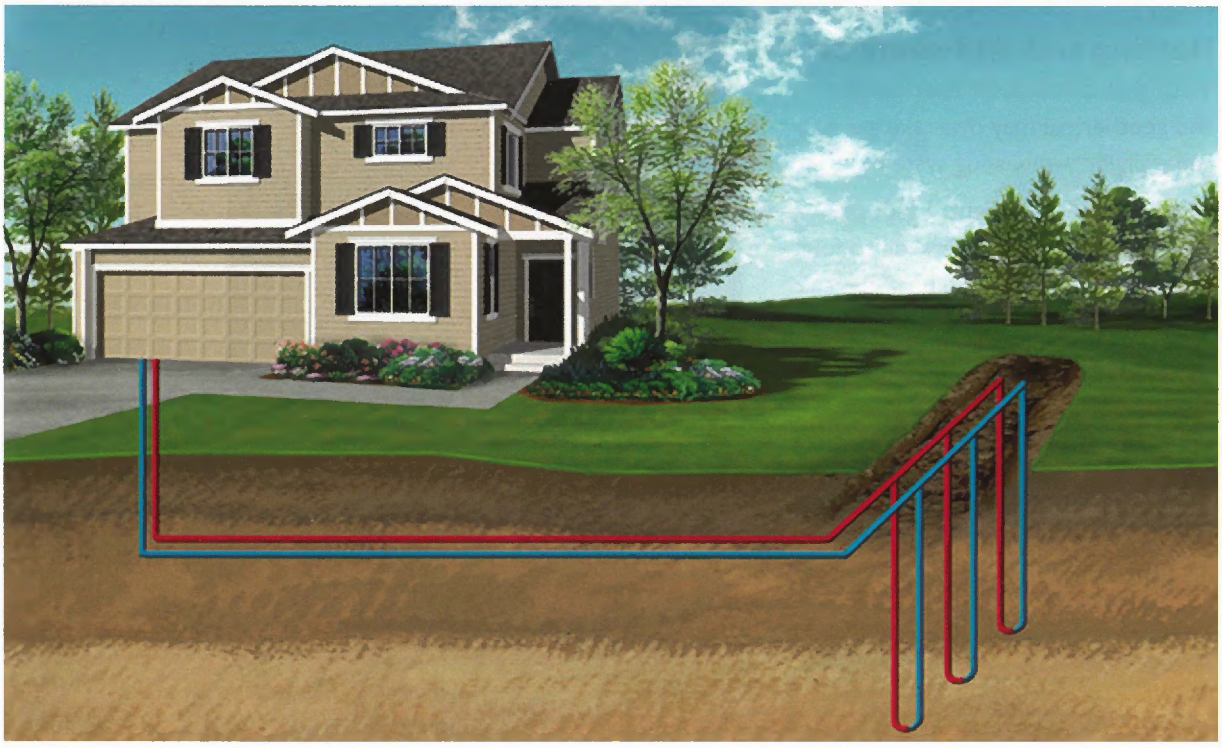
The technique has a strong following in Australia. In 2012 the University of Melbourne was working with the Department of Primary Industries in a major pilot study involving 40 trial properties. Geothermal heating also has a strong following in Canada, New Zealand and the USA.

Geothermal works much as does a reverse cycle air conditioner except that, instead of drawing in outside air, it operates by circulating a liquid through buried piping. Such piping extends laterally if space allows, or if not, up to 100 metres or so downwards.

The earth's temperature close to the surface varies from as low as $7^0$ C to $21^0$ C, (typically $14^0$ C in much of coastal Australia). This constant temperature can be used for cooling in summer. In colder areas it can be used to assist heating in winter.

Currently available units produce 3 to 4 kW of heat for every 1 kW of energy drawn. It is early days for this technology, and its efficiency is bound to improve yet further. Its main benefit for heating is where ambient temperatures are low, and vice versa for cooling.

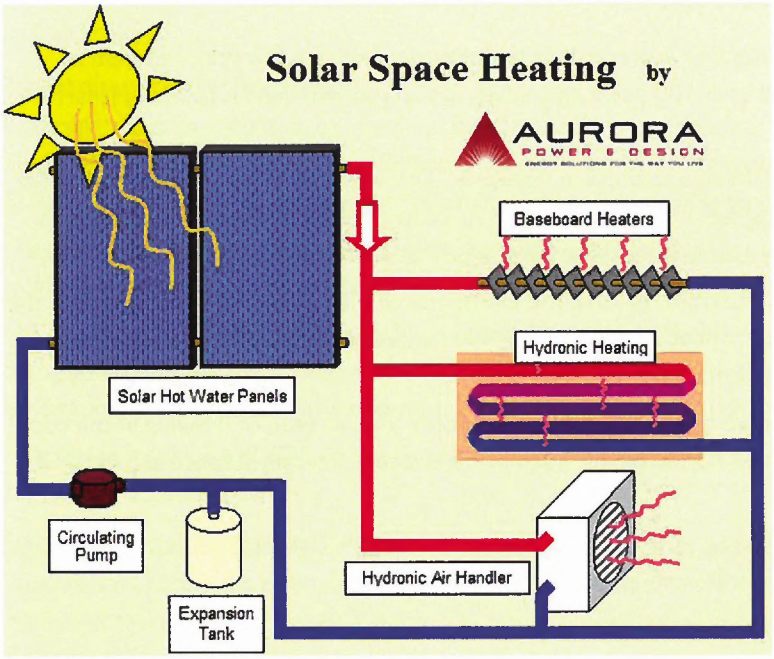
The US Department of Energy describes these systems as capable of 'producing less environmental harm than any other alternative space conditioning technology currently available'.



*Typical geothermal (vertical) installation. Pic: thehydronicsteam.com*

## Solar heated air

Initially developed in Denmark, several companies produce space heaters that blow air heated by the sun into the premises. The two main types heat air alone, or use solar hot water panels for baseboard heaters and hydronic panels. There are also hybrids that heat both air and water.




*Hydronic space heating. Pic: Aurora Power (USA).*

Vendor claims for this technology often specify only the temperature increase but this has no meaning unless the volume of air heated is known. The heat output is unlikely to vary much from brand to brand.

This is a worthwhile area for 'do it yourself' experimentation. A website search will unearth many doing so.

The simplest way to do it is to blow in hot air from a lean-to or adjacent greenhouse.

## Hydronic space heaters

These, in effect are solar water heaters used indirectly to heat air.

The example (left), from Aurora Power & Design in the USA, typifies the approach.

## Transpired solar collector

This relatively new wall technology is simple but effective in applicable situations, particularly for commercial buildings. Outside air passes through an added pre-coated profiled steel sheet that has thousands of tiny perforations, and into an air cavity.

It is primarily seen as an aid to heating in that it provides up to 50% of a building's heating needs or as a preheater for the main heating system.

## Heating and grid-connect

With grid-connect, air heat-pumps and geothermal may overtake gas as a generally better heating system.

Both are very efficient: 1 kW of electrical energy 'uncovers' up to four more kilowatts of usable heat.

*Solar wall. Pic: CA Building Products, UK.*

# Washing Machines

Washing machines vary in their consumption of water and electricity. The two interrelate: not only must water be used with care, but so also must the electrical energy expended in making that water available.

As a generalisation, front loading washing machines use less water and less electricity to run than do top loading machines, but cost more to buy. Given the correct detergent they wash as efficiently as top loaders. They usually take longer per cycle (60 to 90 minutes) but are kinder on clothes.

*Asko W6983 washing machine. Pic: Asko.*

Top loaders are cheaper to buy, use more water and more electrical energy, and cycle faster (typically 30 to 45 minutes). They are harsher on clothes but usually have a good range of cold water cycles.

Select a unit that can readily wash using cold water and use it accordingly. This way you use 80% to 90% less power per cycle. Washing performance is barely reduced providing you use the correct detergent.

## Energy ratings

*As of 2015, the star system for washing machines remains unchanged.*

The star rating system for washing machines works much as for other appliances. It compares machines of similar capacity.

The related data shows consumption for both the cold water cycle and, where the machine heats the water, for the hot water cycle also.

As with many electrical appliances, the efficiency of washing machines has improved in the past decade. There are, however, some very old designs still in production that need to be avoided.

The efficiency difference, on warm cycles, between the best front loader and the worst (slightly bigger) top loader, is an extraordinary 11 times. There is not a big difference, however, between machines on their cold water cycles.

## Water efficiency ratings

From November 2011 an obligatory additional star rating system applied to washing machine water usage. Washing machines with a capacity of 5 kg or more must rate at least three stars. Those with less than 5 kg must rate at least 2.5 stars.

*Water usage star rating.*

## Buying caution

Care needs to be taken when buying. Vendors tend to promote their products' water efficiency rather than their energy efficiency. They do so because many products have five stars for water efficiency, but fewer for energy usage.

## Rebates

State controlled rebates apply from time to time for efficient domestic appliances. For a full and up-to-date list of ratings see www.energyrating.gov.au.

# Clothes Dryers

*Solar - direct. The most efficient and cheapest way! Pic: Hills (Aust).*

thoroughly the washing is spun or wrung out prior to artificially drying, the better.

Major efforts have been made to remedy this: new technology has resulted in several major manufacturers producing six energy star products. One is claimed to use about 1.5 kilowatt hours to dry a seven kg load - but costs $2500. The energy saving is such that a one star unit (still alas on the market) uses close to 3.5 times as much energy as the more efficient products.

The star energy emblem is similar to that on page 19.

In many situations (particularly where there are young babies) some form of non-natural clothes drying is often necessary.

Partial drying using the wind or sun assists, as does postponing doing the washing until the weather improves.

It makes little sense to use an electric clothes dryer whilst the sun is shining, nor does it make any sense to do so in an electric dryer powered indirectly via solar generated electricity.

## Dryer types

The simplest and most economic are spin dryers that revolve at higher speed than can washing machines. They do not totally dry the washing, but come close.

The energy drawn by such spin dryers is related to the water removed.

In removing *each kilogram* of water, a typical two star dryer consumes about 1 kWh of electricity.

Because of this, the more

*Clothes dryer six star ASKO-T784HP-01. Pic: ASKO*

# Dishwashers

Most of the previous chapter's comments about washing machines are true also of dishwashers, except that dishwashers are front loading, and that most draw cold water that they heat for use. Cold water connection is not *that* wasteful, however, as the machines only heat water for part of the cycle. Some do accept hot water so, if you have a solar water heater, it makes sense to use it for this.

## Energy ratings

With one major exception, the star system and energy ratings are almost identical to those relating to washing machines. Unlike other appliances like fridges and washing machines, dishwashers are rated against a specially made and calibrated reference machine - a Miele G590 dishwasher. It is from this, that the dishwasher Washing Index and Drying Index is derived. The tested dishwasher's performance must exceed that of the reference machine.

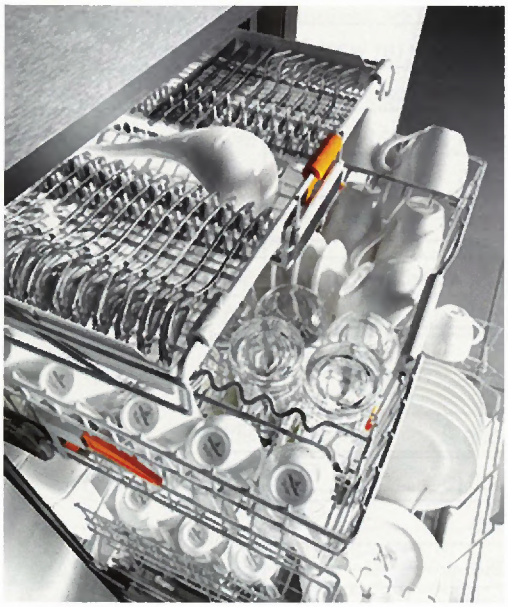
*Smeg stainless steel built-in or freestanding dishwasher DWA157X. Pic: Smeg.*

With most appliances it makes little sense to buy one that's bigger than you need but dishwashers are a curious exception. Most of those that handle 10 or more table settings use physically less energy and water than almost all the machines with fewer place settings, i.e. less *absolutely* – not just pro rata their size. This seeming anomaly is probably because the market for the 10-plus setting units is larger, and development has concentrated on this sector.

## Saving energy

Most dishwashers can cope with scraped but unrinsed dishes. Don't waste hot water doing so.

Run the machine only when it is full and either use the economy drying cycle or, better still, let the contents dry naturally.



*Many 10-plus table setting dishwashers use less energy than their smaller counterparts. Pic: Miele.*

No matter the brand dishwasher you have, you can save energy and water by filling it completely before running it, choosing the economy cycles, and avoiding heat drying options.

| Brand & model | Star rating | Place settings | Energy usage |
|---|---|---|---|
| Siemens SN26E281AU | 4 | 15 | 670 watts |
| Bosch SMI50E45AU | 4 | 14 | 616 watts |
| SMEG DWAFII52T | 4 | 15 | 670 watts |
| Baumatic BDW65W | 3.5 | 14 | 723 watts |
| Fisher & Paykel DW60CCW1 | 3.5 | 14 | 745 watts |
| Venini VDW71W | 3.5 | 14 | 724 watts |
| Hotpoint HPDW06BISS | 2 | 6 | 523 watts |
| Classique CL45DSS | 1.5 | 8 | 805 watts |
| Andi AF456EX | 1.5 | 8 | 805 watts |

*As can be seen here, the larger machines use less energy than the smaller ones. They do, however, cost a lot more initially. Data Energy Australia*

# Power Tools

Most hand-held power tools have electric motors that are reasonably efficient whilst running, but draw several times their running current for a second or two whilst starting. A half-horsepower (375 watt) drill is likely to need 450 watts to be available whilst running, and 1000 watts or so whilst starting.

*Some power tools, such as this Makita 230 mm angle grinder have a soft start. Pic: Makita.*

The older (and heavy) transformer type inverters can usually start any hand-held power tool they are capable of running.

The later transformer-less switch mode units have next to no such excess capacity (see page 50 re this). With these you'll generally need one that is capable of supplying three times the running current of that tool. The list below shows approximate running currents.

Many hand-held power tools are used only occasionally and for short periods. Whilst their starting current is high their addition to the daily draw is usually not serious.

Big motors, such as those that drive cut-off wheels, etc. may draw a momentary 6000 to 9000 watts but some have a 'soft start' feature that limits starting current. Those that do, usually have this made clear in their promotional literature.

It is feasible to run such equipment from solar, and this is often done with the big systems used on outback properties. By and large though, tradespeople using heavy equipment have their own portable generators.

Equipment that draws heavy starting current, or has high peak loads (such as welders) will start and run more readily from an *already running* diesel rather than from a petrol driven generator. This is because the former invariably have heavier flywheels whose momentum assists to overcome the load's high starting draw and changes in load.

| Item | Typical running power draw (in watts) |
|---|---|
| Air compressor 1/2 HP | 750-1000 (but starting surge may exceed 5000) |
| Circular saw (100 mm) | 1400-1500 |
| Circular saw (250 mm) | 1750-2000 |
| Drills (hand-held) | 350-650 |
| Drill press (bench/pedestal) | 500-1000 |
| Garden blower | 2200-2500 |
| Guns – heat | 1500 |
| Grinders (100 mm) | 600 |
| Grinders (200 mm) | 900-1000 |
| Jigsaw | 500-600 |
| Sander/polisher (orbital) | 150-250 |
| Sander (sheet) | 175-250 |

*Typical power draw of tools and devices that can realistically be run from solar for non-professional use.*

# Phantom Loads

All mains voltage devices draw power if left on 'remote'. So do many products that have an external power supply or voltage adaptor, those with continuous displays, and those that charge batteries.

One well-known coffee machine wastes 180 kilowatt hours/year (about half the draw of a decent 350 litre fridge) for trivial assumed convenience. Computers and printers continue to draw power when switched off. So do washing machines and dishwashers. Mains powered door chimes may draw 350 kW hours/year yet be used just a few times a week and for a few seconds each time. It even applies to electric toasters - one costly US-made toaster draws 7 watts if switched off only at the appliance. Some appliances have electric clocks that must be 'on' for them to work at all (even if their time is set randomly).

A phantom load that draws just one watt consumes close to 9 kWh a year: many homes have 30 or more. All need switching off at their wall outlets, feasible remotely by a cord switch made for the purpose.

A major concern are those little black box adaptor power plugs that feed some lights and appliances. Depending on their technology, the larger ones may continue to draw power whether the appliance they feed is on or off. A 50 watt halogen desk light may continue to draw 7-10 watts when turned off only at the light switch.

In January 2013, European Union and US legislation limited all new such loads to 1 watt, and some to 0.5 watt, but much imported product from Asia exceeds these amounts by many times.

*The Belkin F7C005au - basic but accurate. Pic. Belkin.*

## Exposing phantom loads

A simple way of spotting phantom loads is to use an infrared thermometer and checking if the appliance and/or power supply is warmer than its close surroundings.

A better way is to use an energy meter. The appliance to be checked is plugged into the meter, and the meter into the wall socket (some via an extension cord) and turned on. If a phantom load exists, the meter shows the power being drawn. Be prepared for surprises: it is not uncommon for entertainment equipment to draw 75% of its daily energy draw whilst not in use!

Caution is needed when buying an energy meter as most cheap units are inaccurate when measuring low power levels. Clipsal has a good one, but it costs $275. Recommended also is the Belkin F7C005au (around $40) and Jaycar's Powertech Plus MS6115 at about $22.

| Device | Watts | Daily draw (watt hours) |
|---|---|---|
| Video game (hand-held) | 1 | 24 |
| Clock radio | 1.5-1.75 | 36-42 |
| Cordless telephone | 2-2.5 | 48-60 |
| Answering machine | 2.5-3.5 | 60-84 |
| Microwave oven | 3-3.5 | 72-84 |
| Typical TV | 4-5 | 96-120 |
| VCR/DVD | 5-6 | 120-144 |
| Dishwasher | 6.5-7.5 | 156-180 |
| Cable TV box | 11-12.5 | 264-300 |
| Security system | 17.5-20 | 420-480 |
| Coffee machines (some) | 20-25 | 480-600 |

*Typical power draw of phantom loads, and also small but continuous in-use loads of typical consumer electronic devices made prior to 2014, and many made still in non-EU countries.*

# Television & Computers

There have been major improvements in TV technology since the first edition of this book was published, in 2008. Then, the average energy draw of a typical 80 cm TV was about 145 watts. In 2015 it was about 50 watts. The most dramatic improvements have been in the larger units, e.g. Philips' 139 cm unit draws less than 140 watts. Sales of LED TVs are second only to the usually cheaper LCDs (Liquid Crystal Display) and there are hundreds of models available from all major television manufacturers.

## Energy rating

*Panasonic's 125 cm TH-L55ET60A TV draws under 60 watts Pic: Panasonic.*

As with any TV or computer screen, energy draw increases in proportion to the square of the screen's diagonal, but there are substantial variations from brand to brand.

Energy usage is also a function of screen brightness but most TVs have provision for reducing this (retailers usually turn the brightness up to the maximum on their display units). It is well worth reducing the brightness, and also of the viewing area lighting.

The previous 10 star rating system changed in April 2013: a previously four star rated TV was thenceforth rated as one star.

Energy requirement regulations were also tightened. Product imported prior to that date could be sold without restrictions, but from October 2013 onward all had to meet the original four star rating (corresponding to one star on the new scale). As this area is changing fast, refer to http://reg.energyrating.gov.au/comparator/product_types/ for the latest comparative TV energy ratings.

A lot of care is needed when buying as some of the more costly TVs are priced well above those that are more efficient.

## Computers

Some US-made computers are (US) 'Energy Star' rated, but there is no Australian equivalent. The screens have similar energy usage patterns as TVs, but it is rare to find computer screens larger than 69 cm (27 inch).

Major gains can be made, particularly with desktop computers, by setting them up in an efficient power management mode. This is usually built into the operating system - (with Windows it is under 'Power Options' and accessed from the Control panel). In some cases energy usage can be slashed by up to 80%.

Plug-in power supplies for laptop and notebook computers draw power when the computer is turned off. Always switch them off at the wall.

To save energy, unplug your power supply after the notebook battery is charged, or use a power board with individual on/off switches. Some operating systems have a 'hibernate' feature that saves active programs and files before shutting off, then restores the same status when the computer is turned on - encouraging users to shut off their computers when not in use. If yours must remain on in the evening for file backup or other purposes (if it is possible) turn off the monitor.

Laptop and notebook computers are more efficient than their desktop equivalents. Their semi-battery operation *necessitates* that. Most use only a fraction of the energy of a desktop unit. Teenagers are likely to resist using a laptop and parents must devise their own ways to cope.

# Rain Water

Non-potable water needs only basic mechanical screening, but for potable use there is a risk of rainwater containing higher contaminant levels. This can be from airborne pollutants, from roofing and roof flashing materials (e.g. lead flashing on older roofs), and from animals or birds leaving droppings on roofs and gutters. Screens are essential to prevent animals and birds accidentally entering the tank and becoming trapped.

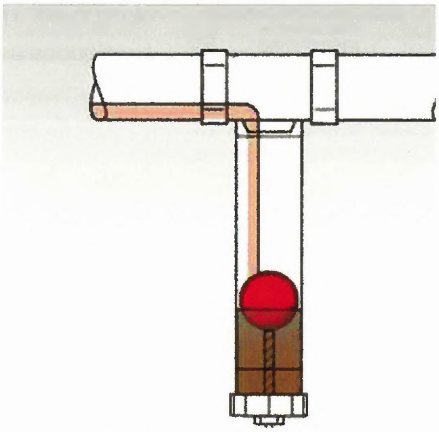
The main requirements include a first flush diverter - a device that fits onto the tank inlet and prevents the initial flow of contaminant-laden water from the roof entering the tank when it rains. It is necessary to clean the first-flush device and catchment area a few times each year. A coarse mechanical screen filter is needed to catch twigs, etc. on the input into the tank. It is also necessary to ensure mosquitoes cannot enter and breed in the tank.

The major risk to health is from pathogens such as cryptosporidium and giardia. Protection against both can be provided by an initial 10 micron filter (and secondary filter of one micron for drinking and cooking). Some suppliers attempt to sell ultra-costly systems, but the above is typical of outback usage (where airborne pollution is less, but there are more small things that crawl and fly). Local councils, state health authorities or rainwater tank suppliers will advise regarding this.

There is no officially recognised standard for filter sizes and their housings, but many manufacturers follow a de facto 'standard' that permits interchangeability. Some produce filters that fit only their own housings - and invariably cost more. This is worth bearing in mind because filters need changing every year.

Above-ground rainwater tanks are cheapest - particularly concrete tanks built in situ. Slimline and wall line tanks fit narrow spaces but are more costly per litre.

An underground tanks saves space and may have greater catchment potential than an above ground tank but, as excavation is needed, installation is costly. For people in rental properties, or liable to move, a very effective approach is to use a number of 240 litre wheeled garbage bins joined by flexible polypipe. 'Seconds' can often be bought cheaply.



*First flush unit - simple but effective. Pic: Water Diverters (USA).*

If feasible, locate the main tank as high as possible, and initially collect the rainwater in a smaller tank able to hold several hours' downpour, then pumped up later via solar power. If the main tank is about 20 metres above the points of use, return feed/s can use gravity alone. Use 40-50 mm piping to reduce friction loss.

*Most potable systems have a fine mechanical screen plus a 10 micron and a 1 micron filter. Pic: Big Brand Water Filters Inc.*

For connections use Blue-Line hose and fittings; available in metric and imperial sizes (the latter has a few that are almost identical, but not totally). In Australia, metric is usually easier to find.

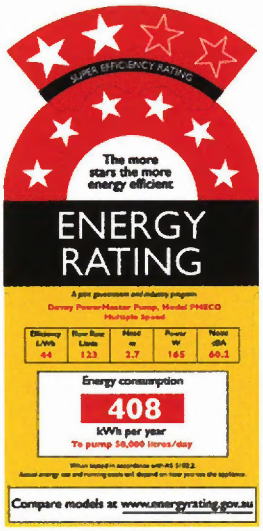
## Legislation

Rainwater usage regulations can be obtained from council and state health authorities. Tank water rebates are currently available from state and territory governments and, in some areas, from local councils. If rainwater is to be the only source, the tank needs to be 50,000-100,000 litres. For garden watering only, a typical urban site needs a 2000-4000 litre tank.

If a rainwater and mains supply are *both* used then the mains water system must be isolated from the rainwater system by a valve mechanism or tap. Your local council or state health department will advise.

# Pumping Water

Where the location permits, an effective technique is to use solar energy to pump stream, bore or rain water to an elevated storage tank, at least 20 metres above main outlets, such that gravity supplies the return pressure. This works particularly well where the uplift pump is programmed to run only when surplus solar energy is available, and overriden to run at other times if required. Many solar regulators and energy monitors have inbuilt programmable switching that can do this, via a suitably rated contactor.




*Pump star rating is voluntary - but can be surprisingly useful.*

The suggested 20 or so metres provides a useful working pressure of 200 kPa (29 psi). This is sufficient for domestic taps, and is acceptable for most washing machines and dishwashers. Timed irrigation valves will work down to 50 kPa (7.2 psi) but may act erratically, or not at all, below that.

Where gravity feed is not possible (or to boost gravity feed) domestic pumps supply water for showers, flushing toilets, washing machines, dishwashers, cooking and drinking, and, when authorities permit, for watering gardens.

Cabins and RVs commonly use small pumps that have pulsating diaphragm valves driven by 12/24 volt dc motors. These pumps are reasonably reliable but dislike not being used. They may need overhauling yearly. None is intended nor suitable for continuous use. They are also noisy.

For larger dwellings and properties, 230 volt pumps are available from irrigation and other suppliers. Most use a centrifugal impellor driven by a standard induction motor. They are quieter and more reliable than diaphragm pumps but, in sizes below 150 watts (rare anyway), their motors are less energy efficient.

## Energy draw

Australia does not currently require pump makers to meet specific energy requirements (except for three-phase units above 0.73 kW), but they can choose to submit pumps for testing and receive a star rating. This situation may change so it is advisable to check the current situation: energyrating.gov.au.

## Pressure systems

The simplest way of supplying water via an electric pump is to have a pump switch located close to each tap. This is cheap and ultra-simple and provides water at more or less constant pressure. Usage, however, may necessitate using both hands, and installation requires electric cabling, and a switch for each tap. This is fine for 12/24 volt pumps, but is not feasible, safe, or legal for 230 volt pumps.

Pressure sensing control is more convenient and efficient: open a tap, pressure drops and the pump is switched on. Close the tap, pressure rises and the pump is switched off again. Such a system is simple to install but has several drawbacks in its basic form.

The main issue is that the pump kicks in almost instantly water is drawn. Then, unless the tap is fully open, water pressure rebuilds rapidly until the pump stops.

In practice, such pumps may cycle on and off every second or two, causing water pressure to constantly rise and fall. Washing machines and dishwashers do not like this, nor do people having showers, not least because the water temperature may vary as pressure varies.

Such on/off control can cause the pump to start and stop thousands of times a day. This shortens pump life and, because they momentarily draw up to twice or more their

*Basic pumps plus a big pressure tank form an ideal simple, rugged and affordable water supply system. Pic: Davey Pumps.*

running current each time they start, energy usage is high. The pump is also likely to start and stop every now and again at night as temperature variations cause minor pressure changes in flexible hoses, etc. Even the tiniest of leaks from a tap does likewise.

Most pumps are designed for specific flow rate, pressure and head. Some are designed to move a lot of water at low pressure, others to pump less water at high pressure. This works well for loads that are calculable and constant, but not where the load varies - as in a home. For efficient domestic and similar use, the variable speed pumps and (particularly) the pressure tank system described below are good compromises. Page 30 shows how to calculate the needs.

## Constant pressure pumps

Available since 2010 or so, pumps that maintain a constant water pressure overcome cycling issues, but some work by running at full capacity even if a tap is only slightly dripping. The unneeded pressurised water is pumped around an internal bypass in the body of the pump. The mode of working is not unlike driving an automatic transmission car with the accelerator pedal permanently bolted to the floor and controlling speed via the brake pedal. They work well enough but are far from energy efficient. Not recommended for solar.

## Variable speed pumps

Rather than throttling an oversized pump, or circulating excess water within the pump body, another approach varies its motor speed according to the flow or pressure required. There are two main types. One varies the frequency of the power to an otherwise standard pump motor intended to run at 3000 rpm from a 50 Hz supply. A costlier but more efficient approach uses a brushless dc motor and associated controller. For the latter, makers claim energy reductions of 70%-80%. Many users confirm this is realistic.

A cost effective use for such pumps is for circulating water in home swimming pools - where the power needed for occasional cleaning is several times higher than needed for ongoing circulation (see pages 31-32).

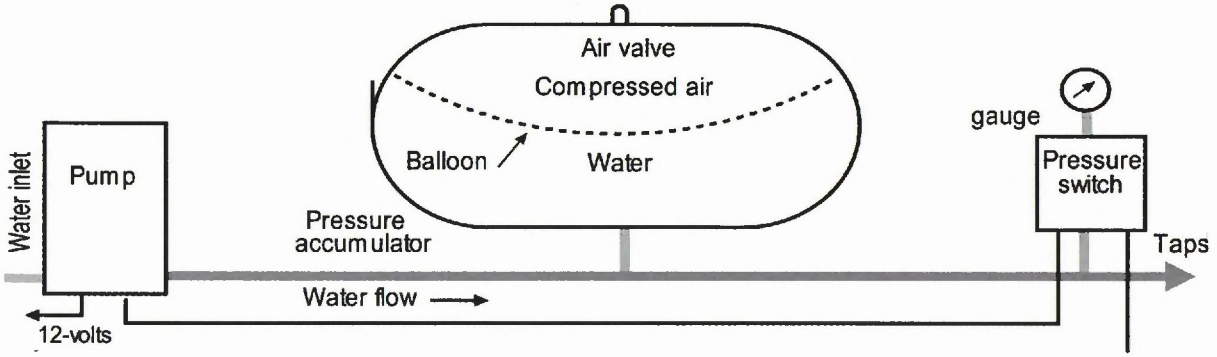
## Pressure tanks

A pressure tank enables water to be supplied primarily by air pressure. Given a large enough tank, this can reduce cycling from many hundreds of times a day - to often only once or twice.

The usually cylindrical tank contains a strong balloon inflated to just below the pump switch's cut-in pressure. When the pump is initially turned on, it forces water into the tank, partially filling it and compressing the balloon. Pressure builds up until cut off by a pressure switch. At this stage the tank is typically half full of water and half full of compressed balloon.

*These 500-litre pressure tanks are buried for cyclone protection. They are about 1.8 metres high. Pic: author 2007.*

When a tap opens, the balloon provides water pressure until the expanding balloon's pressure reaches the pump's cut-in pressure. The pump then starts up and the cycle recommences. This method work best with large pressure tanks. One of 500 litres will supply about 260 litres of water, using air pressure alone.




*Basic pressure system. The tank and pressure switch is best located within 20 or so metres of the pump. Pic: successfulsolarbooks.com*

This necessitates the pump to run only once or twice a day, typically for four or five minutes each time. The pressure drops very slowly and the change is rarely detectable by users. The pump is chosen to match the requirements of the pressure tank so runs at maximum efficiency.

Our previously owned 10 acre property north of Broome initially had a constant pressure 70 watt pump that drew over 1100 watts a day. It was replaced by a 450 watt pump and two 500-litre fibreglass tanks. Tap pressure dropped slowly during the day but was barely noticeable. Energy draw was reduced to a little over 100 watts/day with no detectable user difference.

Pressure tank operation works well with most washing machines and dishwashers. They tend to be affected by rapid pressure variation but not by the slow change of a pressure tank system.

## Irrigation

Property irrigation systems often rely on bore water. The usual practice is to use an on-line bore pump, but when (not if) the pump packs up, or the bore requires cleaning, irrigation stops too. The following approach was devised to provide a week or so of ongoing water at all times and uses any readily available bore pump that matches the bore's depth and water flow required.

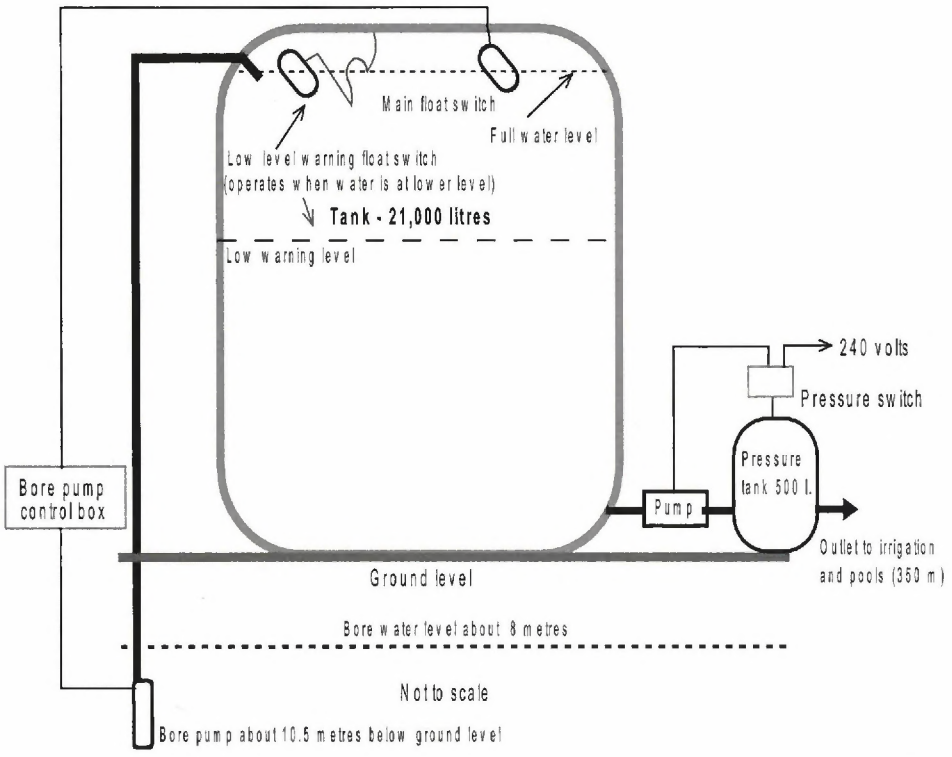
A (solar powered) bore pump is controlled by a timer set to begin pumping up water when the main batteries are fully charged - typically before midday - into, in this example, a nearby 21,000 litre holding tank. An upper float switch cuts off the pump when the tank is full. A secondary float switch starts the bore pump at any time if the tank level drops below 60% full.

A second pump pressurises the irrigation feed. It also supplies external taps, etc.

Bore water can also be pumped up to the main rainwater tank if required (or used for flushing out that tank). This dual-pump system uses more power but provides a comforting stored minimum of 18,500 litres, and a more usual 21,000 litres - a handy resource in bushfire prone areas.

Whatever system is used, energy draw can be reduced by minimising pumping losses. Select large diameter polypipe (see page 30) for main runs, teeing off thinner piping for short runs to drips, etc.

The working pressure can be as low as 70 kPa (10 psi). This still provides adequate drip flow and minimises pipe leaks and failures.




*Irrigation system uses twin pumps. The bore pump normally starts pumping when the battery bank reaches float voltage (typically by 1 pm each day) and cuts off when the level triggers the upper float valve. A second float valve actuates the pump if water level drops below 60%. The irrigation pump is triggered by a pressure switch actuated as pressure changes when a bank of time controlled valves opens and closes. In this version, the control system runs at 12 volts dc. Pic: successfulsolarbooks.com*

Drip-feed systems work well but filtering is essential. They need regular checking for blocked jets and dislodged piping.

Problems can be more readily located by having individually valved irrigation sections – each with its own pressure gauge.

Leakage shows as abnormally low pressure.

Blocked jets show as abnormally high pressure.

## Valve control

A problem with using automated irrigation valves powered by solar is that some use power to keep them turned *off*. They are opened by power being temporarily removed and closed by power being restored. These valves are fail-safe in that they water continuously if power is interrupted, but use electrical energy almost continuously except when open. Their draw becomes serious if many are in use.

The solution is to use 9 volt battery powered 'one-shot' valve controllers. When triggered, these generate a mechanical pulse that turns on an associated water valve. At the end of a preset time, a second pulse turns the valve off again. The valves are programmable for watering days and times. They are long lasting and reliable. Most need a minimum of 10 psi (69 kPa).

*This irrigation valve/timer operates from 70-560 kPa (10-80 psi). It is settable for a wide range of usage. It runs from a nine volt alkaline battery. Pic: Gilmour.*

If the irrigation system's pump can only just supply sufficient water, a pressure tank is of no value. It is, however, effective if the irrigation pump has a larger flow than otherwise needed. In practice, a larger pump plus a pressure tank also provides pressure for other uses whilst irrigating.

## Bore pumps

Bore pumps have a hard life. There are no good cheap ones. At the lower end of the range are 12/24 volt diaphragm pumps. Users say they are effective and efficient (they can run directly from a solar module, i.e. no regulator is needed) but they are almost certain to need servicing yearly. For all but basic cabins, etc. it is better to use a 230 volt bore pump driven via an inverter.

As with most water pumps, bore pumps are designed for specific flows and pressure heads. It is essential to select the right one as bore depths vary from a few metres to 100 plus metres. Unless sure of your ability to do this, seek advice.

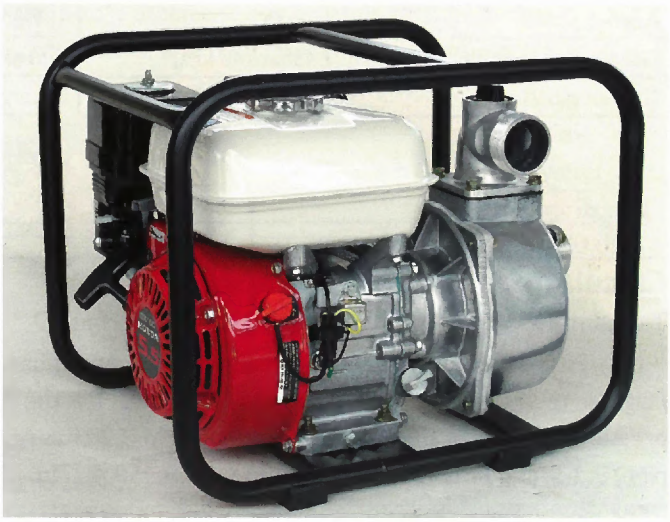
A few companies make efficient variable speed units but, whilst less efficient, basic ones are cheaper, more readily available, more reliable and can be fixed without needing specialised service. Bore pump life varies: many vendors and bore drillers say you are doing well in many areas if you get over four years use. This is certainly true of the Kimberley - where three years is the norm.

## Fire pumps

Fire protection is beyond the scope of this book, but a few comments are included as it concerns tanks and pumping needs.

The primary need is for large amounts of water to be quickly withdrawable from tanks. Most bush brigades throw a loose hose into the tank, but some have facilities to draw from a typically 1.5 inch or 2.0 inch outlet. Check with your local FESA authority for size and thread requirements.

Don't rely on electrical power for fire pumps. Honda and others make petrol driven fire pumps. The smaller portable ones are perfect for putting out spot fires, and light enough to carry anywhere.



*Honda 5.5 hp petrol fuelled fire pump. Invaluable for fire-prone properties. Pic: Honda.*

## Pumping losses - the pipe size and power required

When energy was cheap, and people less energy conscious, little regard was paid to energy needed to force water through pipes, etc. not least because it appears to flow so easily. In reality water resists being pumped.

That resistance is expressed as the equivalent height to which water can be pumped compared with pushing it through 100 horizontal metres. It is aptly called 'head loss' and expressed in metres (or feet) accordingly.

The power needed to pump water through 100 metres of 20 mm polythene pipe at 12 litres/minute is the same as that required to raise it 11 metres. This is called (an equivalent) head loss of 11 metres. For 25 mm pipe, the equivalent head loss is 3.7 metres, for 32 mm it is 1.1 metres, for 40 mm it is 0.4 metre and for 50 mm, a mere 0.1 metre. Tight bend losses add about 5% for each such bend. Sweeping bends are preferable.

The total head of water must include the end pressure required. For non-mains pressure water this is likely to be 150 kPa (21.7 psi) to 300 kPa (43.5 psi): 150 kPa is equivalent to 15 metres of head loss.

The total loss is the sum of friction loss, bend losses, the height through which the water is raised, and the pressure required at the taps.

If pumping over distance, it is worth spending more on bigger pipes and fittings. This enables the use of smaller, cheaper pumps that also draw far less energy.

Buyers often (wrongly) assume that if a pump is rated at 750 watts it consumes 750 watts of electricity. This is never so: water pumps are rated in terms of the work they do (and energy transfer is never 100% efficient).

The work pumps do is often shown as $P_2$. The energy drawn in such pumping is shown as $P_1$. Both are expressed in watts, but often only the former (work done) is shown.

A pump rated at 750 watts is thus able to do 750 watts of work – equivalent to raising 225 litres of water 20 metres in one minute (or 1 HP in our previous terminology). It will draw more than 750 watts when working at full capacity but, as can be seen from the table on the left, the greatest loss is usually due to pipe friction.

| **Flow rate and friction loss – PN 12.5 high density polypipe – per 100 metres** | | | | | | |
|---|---|---|---|---|---|---|
| litres/min | 20 mm | 25 mm | 32 mm | 40 mm | 50 mm | 60 mm |
| 12 | 10.9 | 3.7 | 1.1 | 0.4 | 0.1 | - |
| 24 | | 13.4 | 3.9 | 1.3 | 0.4 | 0.1 |
| 36 | | | 8.3 | 2.8 | 0.9 | 0.3 |
| 48 | | | 14.2 | 4.8 | 1.6 | 0.5 |
| 60 | | | | 7.2 | 2.4 | 0.8 |
| 72 | | | | 10.1 | 3.3 | 1.1 |
| 84 | | | | 13.5 | 4.4 | 1.5 |

*This table illustrates the huge losses if too small pipes are used: it is based on data supplied by Grundfos Pumps.*

| **Average water usage – domestic** | **Each device (litres/minute)** |
|---|---|
| Standard shower head | 15 |
| Economy shower head | 6-7 |
| Standard tap | 10-15 |
| Inside tap + aerator or restrictor | 4-6 |
| Lawn sprinkler | 10-15 |
| Garden tap 12.5 mm | 45 (at 140 kPa) |
| Garden tap 21 mm | 75 (at 140 kPa) |

| **Water pressure systems** | **Water flow required (litres/minute)** |
|---|---|
| Small cabin | 10-20 |
| Medium cabin/small home | 20-30 |
| Average home | 30-50 |
| Large home | 50-90 |

## Calculating pump pressure

To estimate pumping pressure required use the formula:

- Hd - Hs + Hf + Pr = P where: Hd is height (in metres) between pump and highest point. Hs (in equivalent height in metres) is any pressure already available. Hf is the total friction loss for the flow rate. Pr is the pressure required at the tap/s. For example, Hd is 20 metres, Hs is 0, Hf (at 48 litres/minute through 50 mm pipe) is 1.6, and Pr is 150 kPa. Then 20 + 1.6 + 150 = 171.6 kPa (about 24.5 psi).

For most pumps, the volume pumped with the motor's revolutions/minute (rpm), pressure varies as $rpm^2$, power varies as $rpm^3$. One horsepower is the equivalent of 750 watts, 1 psi is 6.9 kPa (kilopascals).

# Swimming Pools

Domestic swimming pools need their water recirculated and filtered at least every 24 hours. To do this most have basic 230 volt induction motor pumps that can be driven by solar, but doing so is inefficient and costly.

We'd intended to obtain our (Broome) pool's recirculating system through the (then) remote area rebate scheme, but all suppliers insisted on either a freestanding bank of solar modules, regulator, inverter and batteries or doubling the size of our main system. Their averaged quote (prior to rebate) was around $60,000 including 'design' and labour. We knew there were better approaches but as no supplier would consider any, we decided to forgo the rebate and designed /installed it ourselves.

The total cost, including concrete and steel for the cyclone-resistant solar mountings and all the electrics, etc. came to less than $8000. As the system ran at a nominal 48 volts dc, a licensed electrician was not required for its installation.

Calculating the pumping capacity needed to recirculate the 35,000 litres of water showed this to be readily achievable by one of the (then) Lorentz Badu Top range of 48 volt dc brushless motor units via an associated MPPT controller.

The pump drew 450 watts and was powered with ease by four dedicated 120 watt Kyocera modules installed on cyclone-proof mounts at ground level (pic on page 95), by the Kimberley's typical daily eight to 10 hours of reliable sun: about 6 PSH. There being no need to recirculate water after dark removed any need for batteries.

Pumping losses were minimised by using oversize filters and piping. Subsequent testing showed that water pressure and flow were almost exactly as indicated on Lorentz's graphs.

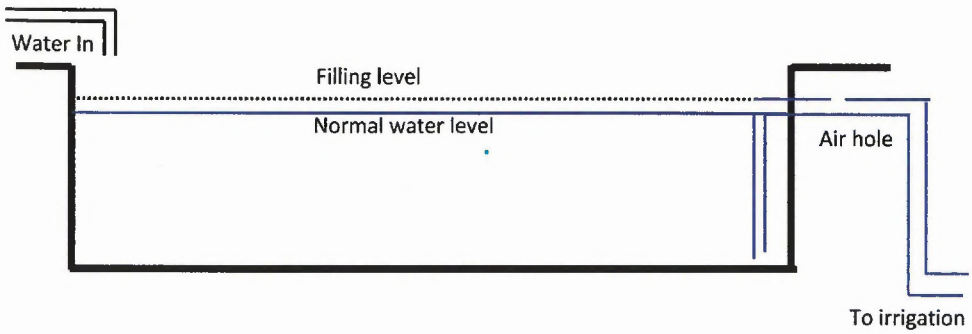
*Lorentz Badu pump after seven years. It runs on 48 volts dc and pumps about 35,000 litres a day using four dedicated 120 watt solar modules. The apparent rust is the Kimberley's Pindan sand that stains everything it touches. Pic: successfulsolarbooks.com*

## Keeping it clean

Pool water is normally sterilised by adding chloride directly, or by passing lots of amps through salt water to produce chloride. The former did not appeal and the latter required too much power.

Thinking laterally resulted in the existing irrigation system's daily water flow being diverted to flow via the pool. This was done via a valve that opened 30 minutes each day. About 2000 litres flows into one end of the pool.

A 50 mm pipe runs from close to the bottom of the pool's other end and extends vertically to normal water level, where it then runs horizontally for about 30 centimetres, and then down into the existing irrigation system (see sketch below).




*A timer valve (not shown) allows irrigation water to fall into the pool for about 30 minutes each morning. As water level rises above the bottom of the U-shaped pipe at the right, it flows down and into the irrigation system. The air bleed hole is essential or the pool siphons dry! Pic: successfulsolarbooks.com*

When the valve opens, water rises to the horizontal section and then down and into the irrigation system over the course of the following two to three hours.

The horizontal pipe has an

essential air breather hole opening in its upper surface to allow air to enter (without it, once water starts flowing, it continues to siphon until the pool runs dry). This technique required so little chloride that it did not bother irrigated plants.

This system was installed in 2003. At the time of selling the property, in August 2010, the pump needed new bearings, but nothing otherwise required changing or modifying. Feel free to copy it (nothing has been or will be patented). Thousands now have (but please acknowledge its source).

*Badu ECOM3-Speed swimming pool pump. Pic: Badu.*

## Recent trends

To cope with pool cleaning, etc. the pump normally used in domestic pools is about four times larger than needed for circulation. To save energy, some installations have a large pump for cleaning, and a second smaller one for circulation.

A more elegant solution is one of the range of high efficiency pumps that are variable speed (230 volt) versions of the 48 volt Badu pump.

The Badu EcoM3-Speed brushless dc motor swimming pool pump has three main switched ranges, each providing variable speed control.

The overall range is from 1000 to 3450 rpm and suitable for pools from 25,000-85,000 litres.

Davey's PowerMaster ECO is an (eight star) efficient pool pump. It has a three speed 'intelligent' control for pool water circulation and filtration, automatic pool cleaning, and a high flow option for all other tasks. The maker claims it uses up to 70% less energy than traditional pool pumps.

The various makers claim reduced operating costs of up to 80% lower energy usage, and reduced noise, but whilst more sophisticated, none appears to compete price-wise with that very low cost, all solar system in Broome.

*The Davey three-speed pool PMECO pump has an eight star energy rating. Pic: Davey.*

*The Broome pool. The four 120 watt modules solar array can just be seen low down at the far (northern) end of the pool. The water nearby is a tidal lagoon - that further back is the Indian Ocean. (The auto water level pipe is at pool right.) Pic: successfulsolarbooks.com*

# Ponds

Outdoor ponds need the total volume of water to be recirculated every two hours or so, and work best if there's a good balance of fish and aquatic plants to prevent algae build up. It helps to have the inlet and outlet positioned to ensure water flow throughout the pool. The water can be kept crystal clear by additives, or preferably by an ultra-violet steriliser as described below.

## Ultra-violet sterilisers

Algea pathogens can be handled by inline UV sterilisers. Their small internal UV light typically lasts 8000 hours. All run from 230 volts ac. Energy draw is typically 1 watt per 100 litres/hour flow.

Blanket weed (spirogyra) can be controlled by an additional unit that, via a cable wrapped around the pipe, disrupts the calcium ions in the water. The units draw a nominal 1.5 watts.

Before installing a steriliser it is worthwhile to first experiment with additives. They may not be required (let alone a steriliser) once a good fish/plant balance is achieved.

*Vitronic 18 watt UV filter copes with 2200 litres/hour flow. Pic: Oase.*

For ponds up to 5000 litres or so, submersible pumps are a good choice. They are silent and require next to no installation. The better examples are reasonably energy-efficient. Many have a magnetic drive from the motor to the impellor. This is worth paying for as it increases reliability.

*This self-made 5000 litre fish pond on the author's previous solar powered Broome property had water circulated by a submerged 24 watt pump under the rock (bottom left), discharging from a hollow log about 0.5 metre above water level at the far end. By using 32 mm hose, pumping losses were negligible. The 12 volt ac pump was run from the main 230 volt 3.4 kW inverter. Pic: successfulsolarbooks.com*

Given the right pump, power needs are minimal but, as with water pumps generally, pond pumps *must* match the application. The normally specified pipe is about 12.5 mm, but doubling that reduces losses (and energy used) by five times.

*The Aquamax ECO and ECO Premium range are efficient, and cope with dirty water. Pic: Oase.*

Ideally, keep pumping height to a metre or so, or the pumped volume will fall off rapidly.

You'll need some sort of inlet filter to protect the smaller fish from being blended by the pump's spinning impellor.

## Solar

Whilst 12/24 volt dc pumps that run directly from solar are cheap and simple, most have a lifespan of 1000 hours running (some less). A solar regulator/battery is not required unless all-night running is planned.

Most fully submersible pumps have a 12 or 24 volts ac motor powered via a small safety isolating transformer via grid-connect, or via an inverter for standalone solar.

You may legally install pumps sold with a plug-in power supply and specifically made and approved for external use. If in doubt, consult a licensed electrician.

*The (UK) Fish Mate pond pumps have outputs of up to 20,000 litre/hour. Pic: Fish Mate.*

Ponds requiring over 5000 litres/hour usually have an external pump. Their location requires care as the pumps tend to be noisy.

*PumpMate PM submersible (24 volts ac) 1500PLV pumps 1450 litre/hour. It draws 20 watts via a weatherproof 230 volt transformer. Pic: PumpMate.*

| Model | Watts | Head (m) | 0.5 m litres/h | 1 m litres/h) | 1.5 m litre/h | 2 m litres/h | 2.5 m litres/h | 3 m litres/h | 3.5 m litres/h | 4 m litres/h | 5 m litres/h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aquamax 2000** | 32 | 2 | 1500 | 990 | 510 | | | | | | |
| **Aquamax 3500E** | 45 | 2.2 | 2700 | 1980 | 1140 | 300 | | | | | |
| **Aquamax 5500E** | 60 | 2.8 | 4320 | 3300 | 2100 | 1140 | 540 | | | | |
| **Aquamax 8500E** | 80 | 3.2 | 6900 | 5520 | 4320 | 3000 | 1740 | 540 | | | |
| **Aquamax 12000ED** | 130 | 5.2 | 10,800 | 9600 | 8700 | 7500 | 6300 | 5100 | 3900h | 2700 | 540 |
| **Aquamax 16000E/D** | 170 | 5.6 | 14400 | 13200 | 11700 | 10200 | 9000 | 7500 | 6000 | 46800 | 1800 |
| **Filtral 2500** | 20 | 600 | | | | | | | | | |
| **Filtral 5000** | 35 | 1100 | 2.3 | | | | | | | | |
| **Neptun 300** | 4.5 | 0.5 | | | | | | | | | |
| **Neptun 600** | 7.0 | 1.2 | 360 | 180 | | | | | | | |
| **Neptun 1500** | 18 | 1.8 | 1080 | 750 | | | | | | | |
| **Neptun 2000** | 25 | 2 | 1260 | 1140 | | | | | | | |
| **Neptun 3000E** | 40 | 3.2 | 2640 | 2250 | 1800 | 1260 | 960 | | | | |
| **Neptun 4000E** | 50 | 3.4 | 3600 | 3150 | 2700 | 2100 | 1500 | 750 | | | |
| **Neptun 6000** | 110 | 5 | 5550 | 5040 | 4500 | 3900 | 3300 | 2700 | 2100 | 1350 | |
| **Neptun 9000** | 195 | 6 | 8520 | 8040 | 7500 | 6900 | 6300 | 5640 | 4860 | 4050 | 2250 |
| **Neptun 12000** | 270 | 7 | 11400 | 10800 | 10080 | 9432 | 8700 | 7950 | 7200 | 6300 | 4500 |
| **Profinaut 21** | 470 | 9.6 | 21000 | 20400 | 19800 | 19200 | 18600 | 17400 | 16200 | 15000 | 14400 |
| **Profinaut 27** | 645 | 10 | 25800 | 25200 | 24600 | 24000 | 22200 | 21600 | 21000 | 20400 | 18000 |

*Energy draw and flow rates (at various heads of water) for typical high quality pumps. Note how flow rate drops off as the pressure head rises. By limiting the height the water is pumped, and by using piping of twice the diameter of the pump outlets (via adaptors) a smaller pump will suffice - and energy usage reduced. The above table has been compiled from makers' published data sheets.*

# Solar Modules

Solar modules turn light into dc electric current. Bell Laboratories is credited with inventing them (in 1954) but the photovoltaic principle behind them was originally discovered by Edmond Becquerel in 1839.

There are various commercial solar cell technologies. All convert sunlight into electricity with efficiencies from 14%-18.5%, hence some solar modules are larger per watt than others. All are rated by a method best described as 'innovative', using Standard Operating Conditions that are far from 'Typical Operating Conditions'. The result is output less than apparently claimed.

## What solar modules really produce

Most solar cells (a module is an assembly of cells) dislike heat. Many vendors claim that their heat loss begins at 25° C, but this is misleading because that temperature relates to the glass-covered black cells under a hot sun. They lose 5% of their output per 10° C increase in temperature and begin to do so at about 5° C. At an *ambient* temperature of 25° C, those cells are at 47°-49° C and power output is down 10%. At 35° C it is 15%.

A further loss is caused by solar modules developing their maximum output at a higher voltage than conventional batteries can accept. It is a bit like driving uphill in too high a gear. Unless you change down, or have an automatic transmission do it for you, the needed output (at higher engine speed) is not accessible.

Maximum Power Point Tracking (MPPT), included in the more sophisticated solar regulators, recovers part of this loss. (See page 39.)

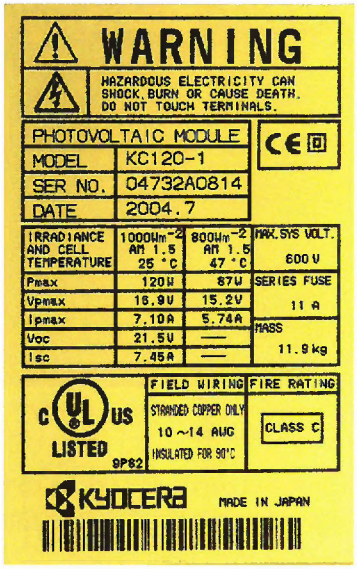
## Nominal Operating Cell Temperature

Total the losses and you'll see that, unless you live on a mountain top in a sunny but cold desert, and have an MPPT regulator, your modules will put out less than appears to be claimed. Module makers do reveal this but in terms called Nominal Operating Cell Temperature (NOCT) that mostly only engineers and technicians understand.

Translated, NOCT assumes an ambient temperature of 25° C, the sun at 48° above the horizon and a breeze of 1 metre/second (3.6 km/h). Using the NOCT rating, a '120 watt' module in much of the world puts out about 87 watts, about 72.5% of that apparently claimed: a bit more in cold parts and a bit less in hot parts.

Grid-connect systems usually incorporate MPPT regulation hence the 85% of system output (admitted by many installers if queried) is about right. A grid-connect system marketed as '1.5 kW' is typically 1.2-1.25 kW.

Amorphous technology modules, (e.g. Uni-Solar, Schott) are only barely heat affected, but are less efficient and hence larger per watt.




*This nominally 120 watt module puts out 87 watts at an ambient temperature of 20° to 25° C. Pic: successfulsolarbooks.com*

## How much sun?

Quantifying solar irradiation is covered on page 7. Solar irradiation maps for Australia are on page 54. These maps relate to mid-winter and mid-summer. In most places the transition is more or less linear, but in some (like parts of NZ's north island) the change can be faster due to rapid onset of cloud cover. Maps for other parts of the world are available from meteorological offices in the areas concerned.

As a reasonably valid generalisation, the highest annual solar input is between latitudes of plus/minus 15°-30°. By and large, areas closer to the equator receive less, mainly due to greater cloud/haze cover.

For stand-alone systems your main interest will be the *lowest* solar input but, as the power drawn by refrigeration is a function of ambient temperature, you need less power in the winter months (unless you have an unventilated fridge in a heated kitchen). With grid-connect your main interest is the yearly average.

## Tracking the sun

Having modules track the sun enables them to capture more sunlight early and late in the day. Tracking is most effective in winter at high latitudes but progressively less so otherwise. Whilst common in an era when module capacity was costly (and/or space at a premium), reliable tracking mechanisms were far from cheap.

As solar module capacity is now relatively affordable, a good compromise in most places is to accept there will be some loss, but to increase the solar capacity to compensate, and have the modules facing true north and tilted at the angle shown in the section on solar module installation - (page 71).

If, as many are now doing, you intend to use one or more of the ultra-efficient reverse-cycle air conditioners for winter heating, consider increasing the tilt angle to as much as 50°-60°. This will make a major difference in winter and not that much of a loss in summer. Do not be overly concerned about azimuth - i.e. that the modules face true north. Errors of 5 to 7.5 degrees result in more input in the morning and less in the afternoon - or vice versa - but there is usually only a few per cent difference in daily input. Most is captured between 10 am and 2 pm. See also pages 58-61.

## Shadowing tolerance and loss

*Solar shadowing. There will be virtually no output from the bottom row. Pic: source unknown.*

The term 'shadow tolerance' when used in connection with solar modules is often misused. None work at all in full shade. They must have at least diffused sunlight. What is being referred to is the amount of output lost if *part* of the module surface is fully shaded, e.g. by a tree branch.

Shading a non-amorphous module by more than 20% or so effectively shuts it down. Amorphous modules lose output more proportionally: shading 20% of their area loses about 30% of their output and so on. See also page 10.

## Weather effects

It is rare to have no solar input but total cloud cover may cut it by three-quarters. Heavy rain may reduce it to 5% or so, smoke and haze from bushfires to almost zero.

The highest input is generally obtained on sunny days with scattered light cloud. Then, and particularly close to the sea, or to a reflective surface like whitish sand, light may be bounced upward from such a surface and then down again from a white cloud. It is not unusual to have 20% or more increase for a brief period.

## Buying solar modules

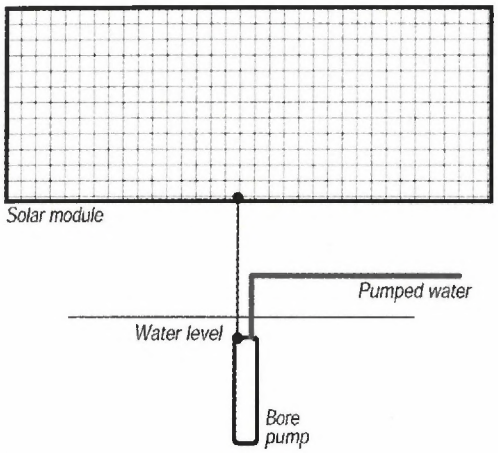
Solar equipment pricing is usually an integral part of an accredited solar supplier's quotation. It is rarely itemised. This is not of *major* concern as buyers need only to know whether or not the total is competitive.

If implementing your own system it pays to shop around for individual prices. Many suppliers offer substantial discounts to those buying modules and batteries in bulk.

There is a minor trap when buying modules. Some are intended specifically for grid-connect systems and are rated at voltages that are not multiples of 12 (volts). These are fine for stand-alone systems if used with a suitably compliant MPPT regulator but not necessarily otherwise. Many RV owners seeking bargain modules on eBay have been caught out by this.

# Solar Modules - voltage, current & power

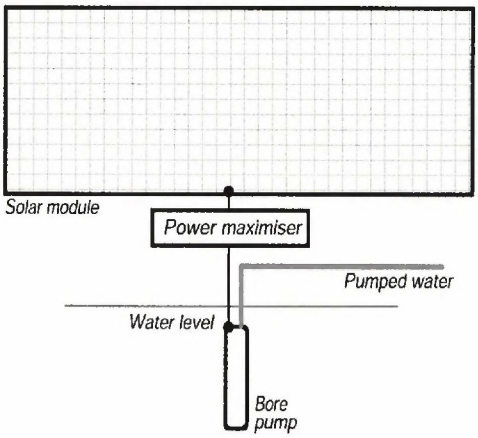
Solar modules (and batteries) can be interconnected for various voltages and currents but the same number of units of the same wattage *always* results in the same amount of energy being captured, storable or available. You can increase amps (with volts remaining as is) or increase volts (with amps remaining as is). But no matter *how* you do it, the total wattage (available power) is always the sum of the wattage of individual modules. There is no 'silver connection bullet' that provides the silicon version of a free lunch.




*A basic system – single solar module and pump.*

For totally basic stand-alone systems of 100-500 watts used perhaps for water pumping, it is simplest to use 12 volt modules. These are available from a watt or so to about 130 watts and, as shown (left), a single 12 volt module of the appropriate size is often all that is needed.

For really basic pumping systems it is not necessary to have a solar regulator to control the voltage but, as shown (right), a so-called power maximiser can be included to improve efficiency.

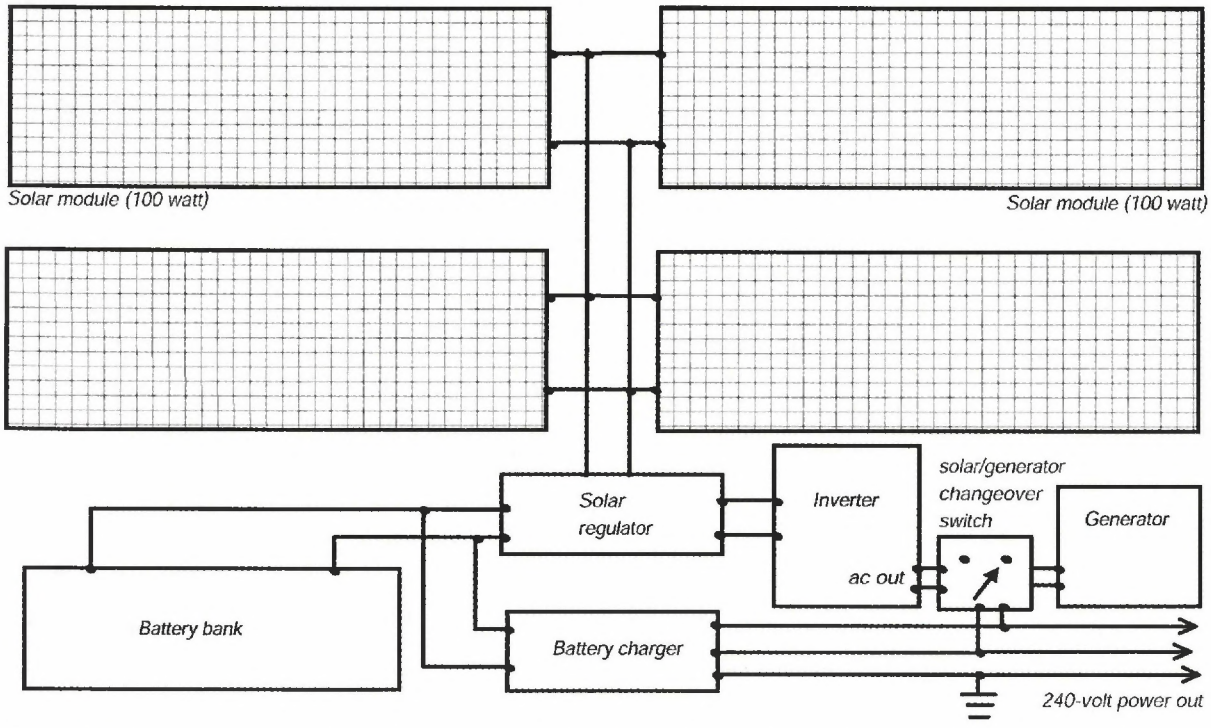



*Here, a power maximiser (a basic MPPT unit - page 39) improves efficiency.*

## Power

Power is a measure of the rate at which work is done. In all forms of engineering it is measured in watts (750 watts is the equivalent of what we used to call 1 horse power).

One watt is that produced by one volt and one amp. Were a solar module to produce 8.33 amps at 12 volts




*This is a typical home/small-property system. It is shown here with four 12 volt, 100 watt solar modules in a 12 volt series/parallel configuration.*

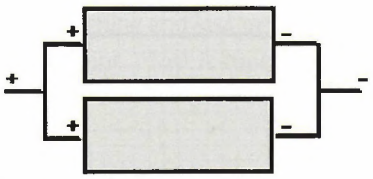
it would generate about 100 watts, but, as explained on page 35, solar modules produce less than seemingly claimed, e.g. if charging a battery at 12 volts that module's actual output is about 5.9 amps (71 watts). At 12.8 volts it is 75.5 watts.

It is essential to remember that (unless the NOCT rating is quoted on the packaging, and it rarely is), the above correction is needed.

## Increasing current

Whilst single 12 volt modules are available with outputs of up to 30 or so watts, most installed solar systems require far more output than a single 12 volt solar module can supply. This is achieved by using higher voltage solar modules, and/or by connecting solar modules together to increase current, increase voltage, or both.

For systems up to 1000-1500 watts it is common to use multiple 12 volt solar modules, in so-called parallel, to increase current. This is done by connecting the solar modules' positive terminals together, and likewise the negative terminals (right). The resultant current and wattage is the sum of the individual modules. Modules of different wattages can be paralleled as long as they are all of the same voltage. The output is the sum of their individual wattages.



*Parallel connection*

It is thus fine to parallel connect a 12 volt, 100 watt module, and a 12 volt, 50 watt module. The output will be 12 volts at 150 watts.

## Increasing voltage

Once beyond 1000-1500 watts, the current (of about 85-125 amps at 12 volts ) requires such heavy cable that it is better to have the solar array, and associated battery bank, running at 24 volts or more. This is done by using 24 volt modules, or by connecting modules in series, i.e. end-to-end as shown below right.

The resultant voltage is the sum of the individual modules' voltages. The current remains the same as if it were one module.

Series connected solar modules must all be of the same, or very similar, current output. The overall current output is limited to that module of the least current output. Voltages may however be different. The total voltage will be the sum of each individual module's voltage. To obtain 24 volts it is thus feasible to series connect 12 two volt batteries, four 6 volt batteries or two 12 volt batteries.

*Series connection*

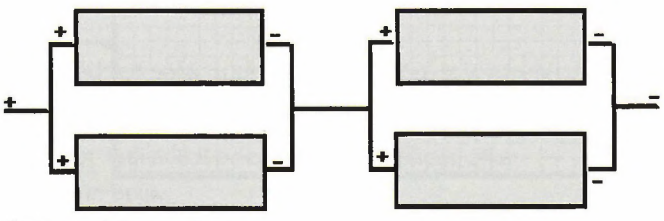
## Increasing voltage *and* current

Stand-alone systems generally have the solar array running at a nominal 72 volts (up to 110 volts dc off load) with battery banks connected to provide 48 volts. This is partially for reasons of safety, and because it also legally enables non-licensed electrians to build and maintain them.

To increase both current *and* voltage, it is feasible to connect *strings* of series connected solar modules in parallel as shown below right.

Where truly serious power is required, it is usual to have two or more sets of the above with suitably compatible paralleled inverters providing whatever is needed.

It is also possible to set up similar inverters to provide 415 volt three-phase output.



*Series-parallel connection*

## Grid-connect modules in stand-alone systems

Another possibility is to use a suitable MPPT regulator (page 39) in conjunction with (the often bargain priced) higher voltage solar modules made for grid-connect systems. Care is required to ensure the MPPT regulator can cope, but many accept up to 110 volts - with provision to charge 12, 24, or 48 volt batteries.

# Solar Regulation

The voltage across a solar module varies with the intensity of the sunlight acting upon it. That voltage must be controlled to safeguard connected appliances, and to ensure associated batteries are optimally charged.

The crudest and *non*-recommended way of doing the former (but not the latter) is via 'self-regulating' solar modules. These have a lower than normal voltage, and self-regulate in a manner akin to starvation being a 'self-limiting diet'. Most of the time their output is too low to more than half-charge a battery but, if used without a solar regulator, they can occasionally produce voltage high enough to damage.

The most basic solar regulator is a voltage sensing switch between the modules and the battery. At low battery charge, the switch remains closed. As the battery approaches full charge the switch may open and close every second or so. These regulators cost $35 to $100 or so and handle about 10 amps. They do not charge very efficiently, and are borderline acceptable even for basic systems. Not recommended.

Sophisticated regulators cost $250 upwards. They control charging current as well as charging voltage. Most are programmable to handle a range of solar input voltages (typically 12 to 48 volts) at their rated current. Some handle input voltages higher than that, and are settable for a wide range of battery voltages.

Up-market regulators need programming for time, battery type, voltage and capacity, etc. Programming is not difficult once the manual has been read a few times. Teenagers are good at this, but rarely at explaining how.

Conventional regulators have an inherent loss with (for example) 12 volt batteries that require 13.2-14.7 volts to fully charge, but solar modules typically produce maximum power at about 17 volts. Basic solar regulators cannot access that voltage in between - resulting in a proportional loss of energy.

*This Outback Power MPPT regulator handles up to 70 amps. Pic: Outback Power.*

## MPPT regulators

The Maximum Power Point Tracking (MPPT) concept reduces that energy otherwise inherently lost. An MPPT regulator accepts a wide range of input voltage - from as low as 9 volts up to a typically nominal 72 or so volts (an actual peak of about 110 volts), yet is programmable to charge 12, 24 and 48 volt batteries. Some accept 300 volts or more. They optimise the input by 'juggling' volts and amps to maximise energy input, and the battery bank's needs at all times. Electrically, they are intelligent dc-to-dc converters.

These MPPT units cost more but are particularly effective in very cold places (where solar modules produce higher voltage) by enabling that higher voltage to be exploited. Also, when voltage is low due to little sun, they increase voltage, at the expense of current, to enable the battery bank to charge earlier and later each day.

Vendors typically claim 'gains' of 20% to 30%, but the product can only recover energy otherwise lost or not otherwise accessible (a reality more likely to be 10% to 15%). The often claimed increase in energy *captured* exists only in their vendors' imaginations.

A benefit of MPPT is its ability to accept high voltages - thus enabling lighter cabling. It is particularly worthwhile where the solar array is at some distance from the battery bank. The technology is usually built into up-market solar regulators integral with grid-connect inverters. It is also built into many non grid-connect regulators and even solar modules.

## The state of charge

The more up-market solar regulators usually include monitoring that shows what is happening to the battery and solar system generally. It is also feasible to add this to those regulators that have no readout, or where that existing is inadequate. The need for monitoring will be clearer after reading the next two sections.

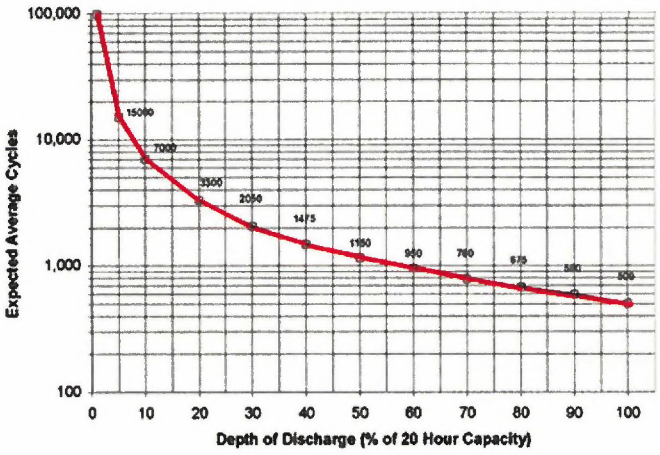
# Batteries

With stand-alone systems, a battery bank handles loads beyond the solar input's immediate ability to supply, and stores excess solar energy for use outside daylight hours and during periods of little sun. With grid-connect systems, there is already an increasing trend to include battery back-up. This is likely to escalate.

The cost of solar capacity fell by 75% or so between 2010-2014: that of battery capacity rose slightly. The latter cost increase does not necessarily increase overall system cost. This is because adding more solar capacity not only enables quicker charging but also increases input during periods of little sun. It is thus feasible to maximise the now low cost solar capacity, and reduce high cost battery capacity.

## Battery types

Conventional batteries provide energy over time but, as the graph below shows, their lifespan is shortened if they are routinely deeply discharged. Their description (of 'deep cycle') can thus mislead.




*Deep cycle batteries - typical life span vs depth of discharge. Graph: copyright Woodbank Communications Ltd mpoweruk.com*

If discharged overnight by 15% (about 85% remaining), good quality batteries withstand 4000-5000 cycles of such use. Rare deep discharges do little harm, but battery life is substantially reduced if done frequently.

In essence, battery makers sell usable amp hours. You can use a few for a long time, or a lot for a short time, or optimally in-between.

Gel cell and AGM batteries cost more than conventional lead acid batteries, charge faster, and suffer less harm if deeply discharged many times. They are a good buy for remote cabins, and for people who would sooner pay more and forget that batteries are there. They require the associated solar regulator and battery charger to be specifically programmed for such use.

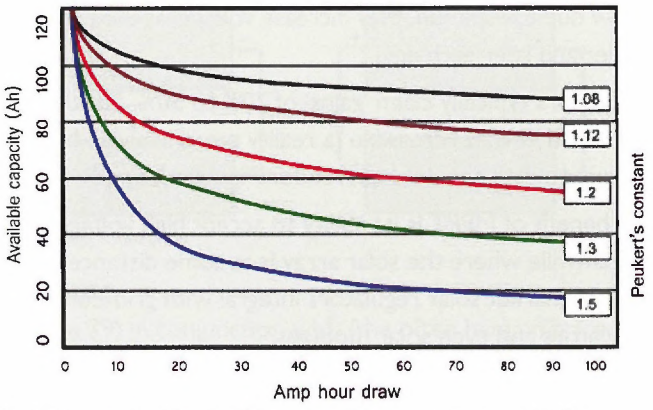
Lithium-based (LiFePO4) batteries are claimed to be ultra-rugged, able to be almost fully discharged without harm, and to have good longevity. Their management and charging are more critical than for most other battery types, so it is advisable to buy both battery/s and charger from the same supplier. Some insist on it as a condition of the warranty.

In late 2015, lithium batteries were about one third the weight, and size of other types of battery of similar usable capacity, but cost three to four times the price.

## Battery capacity

Do not assume the bigger the battery bank the better: that is like having several bank accounts (each with overhead costs) for the same income. If energy is not there to save, increasing battery capacity (alone) can only *increase* overall losses.

As the table on the right indicates, there is a non-linear relationship between the rate of discharge and *available* battery capacity. This was recognised by Peukert in 1897 but his resultant equation tends to be misinterpreted.




*Available capacity of lead acid batteries of Peukert exponents of 1.08 to 1.5. The available capacity drops disproportionately at high current draw. A typical deep cycle example has an exponent of 1.3 or so. Pic: courtesy of Battery University (and based on von Wentzel 2008).*

Peukert pointed out that the amount of energy that can be drawn from a charged lead-acid battery is related to the *rate* at which it is drawn. If a heavy discharge is *intermittent*, however, the battery recovers. This effect is shown in the graph (page 40). The blue line is effective battery capacity. Some battery makers' provide a Peukert number (typically 1.25-1.4): the numerically lower the number the greater the amount of energy that can be accessed *at a high rate of current draw.*

Where Peukert's effect matters is in small systems (such as with cabins and RVs) where a small capacity battery is suddenly hit with the typical 150 amp draw of a microwave oven. Whilst the battery may have considerable remaining capacity, it cannot sustain that 150 amp draw without its voltage dropping too low for the microwave oven to continue working.

Claims have been made to the effect that lithium batteries are immune from the Peukert effect - that they have a Peukert number of 1.0. It is very close to that - but it *cannot* be 1.0. That is contrary to basic laws of thermodynamics. For a full explanation see: http://caravanandmotorhomebooks.com/what-peukert-really-meant/

## Interconnecting batteries

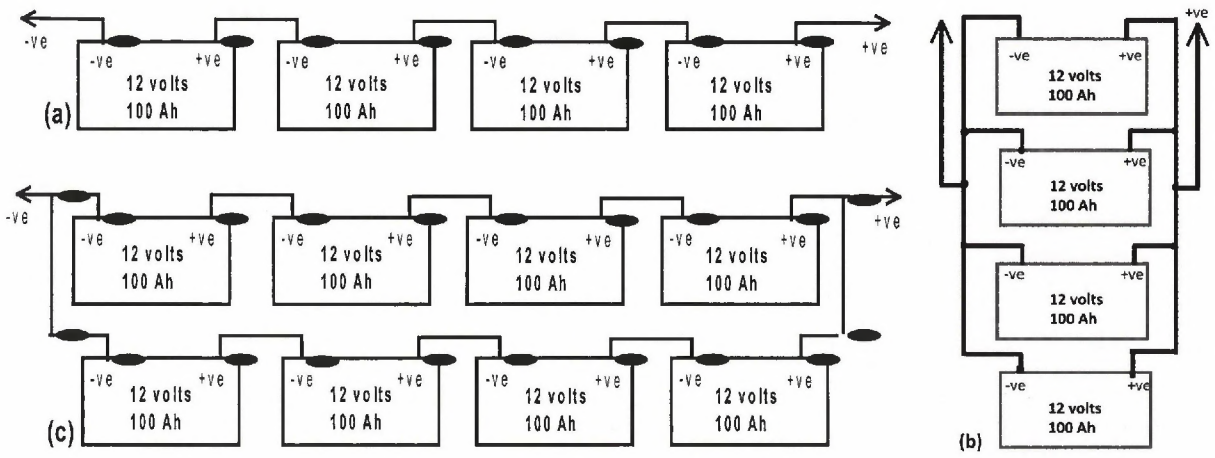
As with solar modules, batteries can be interconnected in various ways to increase voltage and/or current. This is usually necessary (at 12 volts) as single batteries larger than about 150 amp hours are too heavy to move safely. The method of interconnection is similar to that of solar modules but there are additional restrictions, including that it is not advisable to interconnect new and old batteries.

Current is increased by parallel connection. Care is needed to ensure all batteries receive identical charge. Some people maintain that parallel connection should be avoided, however the Exide Corporation (one of the world's largest battery makers) advises that, as long some precautions are taken, it is fine to parallel connect up to 10 batteries. Exide adds that, if paralleled, all batteries must be of the same voltage, but can be of various amp hour capacities. The total current output is the sum of the individual batteries' current outputs.

Voltage is increased by series connection: positive to negative, positive to negative, etc. Four 100 amp hour 12 volt batteries connected in series produce 48 volts at 100 amp hour (4800 watt hours). Any number of batteries can be connected in series as long as they are all of the same amp hour capacity. With series connection, voltage is additive. Current remains the same.

In practice, almost all large systems use parallel connected strings of series connected batteries. In the sketches below, (a) shows four series connected 12 volt, 100 amp hour batteries, (b) shows the same batteries connected in parallel, (c) shows two paralleled strings of series connected batteries.

As with solar modules there is no 'magic bullet' way of interconnecting batteries to obtain 'more power.' No matter how connected the same number of similar batteries will *always* store and deliver the same number of watt hours.




*Battery connections: (a): series connection – 48 V at 100 Ah (= 4800 watt hours) (b): parallel connection – 12 V at 400 Ah (=4800 watt hours), (c): series-parallel connection – 48 V at 200 Ah (9600 watt hours). Pic: successfulsolarbooks.com*

# Battery Charging

A battery is charged by applying a voltage across it that is higher than it has at the time. The greater that voltage difference, the greater the charging current, and the quicker the battery will charge. No deep cycle, gel cell or AGM batteries, however, withstand charging at internal temperatures above 50° C.

Subject to the above, conventional lead-acid deep cycle batteries can usually be charged at 15% to 20% (in amps) of their amp hour capacities, e.g. a 100 amp hour such battery can be safely charged up to 20 amps or so. Ideally, the charger should be capable of charging at not less than 10% of that bank's amp hour capacity. A 500 amp hour battery really needs a 50 to 75 amp charger.

Gel cell and AGM batteries can be charged at higher rates (typically 30%-40% of their Ah capacities) but charging at much over 15% is rarely required for home/property systems. Lithium batteries withstand very high charge and discharge rates. They require specialised battery management systems to ensure equal cell charging, etc. These are essential - but not always supplied as part of the battery package. Their charging should be discussed with the battery vendor.

Charging any costly battery should never be attempted via a conventional hardware store type charger. Such chargers are adversely affected by changes in the voltage going into them and liable to wreck batteries. Take this seriously: overcharging is easily identifiable by battery makers, leaving you without redress.

Good chargers are not cheap: a good rule is to pay about 20% or so of the price of the batteries they charge. Buy only from specialised electrical and solar suppliers, not hardware chains. The charger should be programmable for conventional lead-acid, gel cell and AGM batteries.

Many pre-1990 battery chargers used heavy, bulky and inefficient transformers to reduce the 230/240 volt ac input to the lower dc voltage required. They were typically only 70% or so efficient (if so used, that necessitates more solar capacity). The later switch-mode transformer-less chargers of today cost much the same but are smaller and lighter. Some are over 95% efficient. Switch-mode chargers (page 45) may not run satisfactorily, or at all, from some generators.

## Charging area

*This battery rack self-built from industrial strength galvanised Dexion has bracing gussets at every corner and shelf. It carries 1500 kg and was tested at 5000 kg. Pic: successfulsolarbooks.com*

A secure and cross-ventilated area must be provided for the battery bank. Details of the vent sizes required are on page 75.

Large batteries are extremely heavy. The 12 volt, 230 amp hour units, pictured left, total over 1.5 tonne.

The racks not only need to be able to readily support the weight, but must be braced to ensure they do not collapse sideways or diagonally.

The battery charger should preferably be located in a separate but adjacent secure area. Details of battery and battery charger installation are on pages 75-76.

# Monitoring the System

For all but the very smallest systems (such as a solar module and a pump) you need to know how well or otherwise the system is working, particularly the battery bank's ongoing state of charge. This is not feasible by checking voltage because deep cycle batteries react very slowly to change, especially whilst recovering from heavy loads. A well charged battery may present as close to fully discharged directly after supplying high current. This can mislead to the point where still sound batteries are discarded following 'too low' voltage readings. Conversely, a worn out or damaged battery is likely to show a close to fully charged voltage - which collapses rapidly under load.

A truly accurate voltage measurement requires the batttery bank to have rested off charge, and off load, for about 72 hours.

The only reliable way to obtain an instantaneously meaningful reading is the way you keep account of money. Note what comes in, deduct what goes out – and deduct the bank's ransom for using your stored money meanwhile. The result is what you have left. No-one has ever put that result more succinctly than Charles Dickens (below).

Nowadays, all but the cheapest of regulators have monitoring inbuilt. Where, there is none, or where what you have is too complex, you can add an energy monitor, such as that shown on the right.

*Xantrex LinkLITE Energy Monitor selectively displays voltage, charge and discharge current, consumed amp hours and percentage remaining battery capacity. Pic: Xantrex.*

Monitors show the charge coming in, the total for the previous day, and the current going out. There is likely to be all sorts of other information, plus facilities for turning things on and off under pre-settable conditions, e.g. 'start the generator if battery voltage drops below whatever, and stop it again when the batteries are 98% charged'.

Where energy monitoring is included within the regulator, the current drawable is limited by that regulator's rating. This can be overcome by adding a current shunt (page 76).

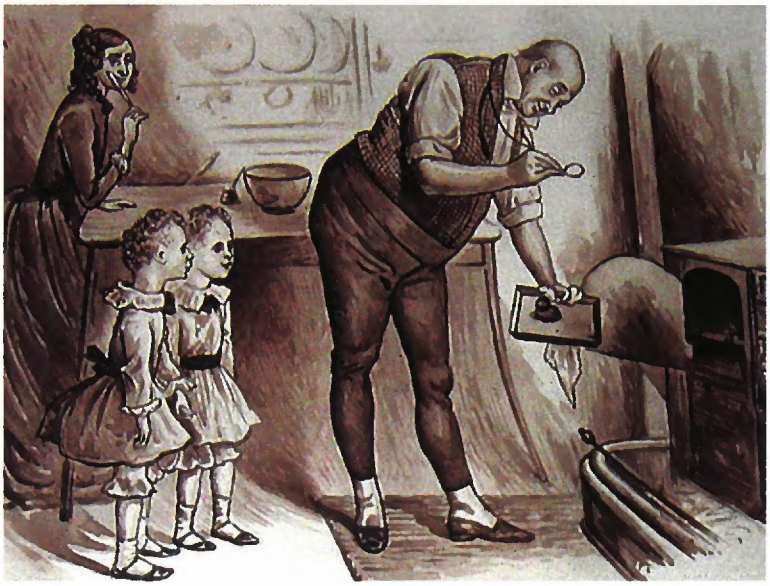
The shunt monitors everything going into and out of the battery, and feeds the information to the solar regulator for display on that unit's screen, or on a separate readout. Most also store monthly data, handy for fault finding - even if you cannot correct the problem yourself.

Do not stint on energy monitoring. The need may not be obvious - but it really is necessary.

Some vendors install monitoring accessible *only* from the supplier's premises. Insist on the data being accessible on site. Often the 'low input' (for which you may be charged hundreds of dollars to fix) requires only that the modules be cleaned, a tree branch trimmed, or a battery lead re-tightened.

Monitoring will at least give you some idea of what to look for.

The units need programming, but whilst the instructions may first appear daunting, it is usually easy once they've been read a few times.



*"Annual income twenty pounds, annual expenditure nineteen nineteen and six, result happiness. Annual income twenty pounds, annual expenditure twenty pounds, nought and six, result misery." Solar is like that too. Quote: from Mr McCawber in Charles Dickens' novel,* David Copperfield. *Pic: original source unknown.*

# Generators

Whilst possibly optional with systems that have fridges that run from LPG, a generator will sooner or later be required for a home or property system. Its size and type depends on how you wish to use it. It can be as an integral part of the system, to get yourself out of strife if something goes wrong, or to cope during spells of little sun or to run occasional extra-heavy loads. Most outback users opt for diesel power but, for only occasional back-up in overcast conditions etc, petrol powered units, such as the quiet Honda/Yamaha/Suburu inverter generators, are cheaper, smaller and quieter.

*Honda EU 3000 uses about 1.8 litres/hour to produce a continuous 2800 kVA. Depending on the load, noise level varies from 52 dB(A) to 65 dB(A). Pic: Honda.*

Whatever the proposed use, a vital consideration is that the generator not damage anything connected to it. This can and does happen with ultra cheap petrol engined units. Apart from a total lack of voltage regulation, when one such runs out of fuel it splutters to a halt. This generates voltage spikes that damage the generator, and anything connected to it at the time. This is a *very* real risk for buyers who believe that Lexus performance can be bought at Lada prices.

Petrol inverter generators do not suffer from the above. They are quiet and reliable, but their *continuous* use at full load is typically limited to 80% of their rated output. Their life span too is limited.

## Petrol vs diesel for long-term use

For frequent long-term use it usually best to buy a good quality diesel-powered unit. A really good example will cost three or more times that of a petrol driven unit of the same output, but will use 35% or so less fuel and likely to last several decades.

There are two basic types of diesel generator which, for 50 Hz (cycles/second), run at either 1500 rpm or 3000 rpm. The 1500 rpm units cost more and may outlast their owners. The 3000 rpm units are cheaper, but whilst their reliability/longevity is acceptable, they do not rival their slower speed brethren.

Diesel generators have the further advantage that their high compression ratios necessitate heavy flywheels that have a great deal of momentum. As long as the generator is running, the flywheel's momentum will supply energy to assist starting heavy loads. A good diesel generator may thus start a load that is beyond the capability of a similar sized petrol unit.

For general property use, there is a good case for an additional portable 5 kVA or so petrol unit. They cost about $1500. (A diesel unit is less suited to occasional use as the fuel tends to fungal build-up – but that is preventable by additives obtainable from truck fuel stations).

## Battery charging from a generator

Some generators have a 12 or 24 volt dc output but even if labelled 'battery charging', the output is almost always too low (in both voltage and current) except to partially charge a car starter battery. Instead, use a high quality battery charger driven from the generator's 230 volt output.

A few specialised generators (both petrol and diesel) generate 12 or 24 volts dc only. They eliminate the losses involved within conventional transformer type chargers (that need a generator with an output about twice that of the charger's output). Dc generators filled an earlier need, and still have a place in specialised applications, but a better approach now is to use a conventional 230 volt ac generator and a switch-mode charger. Such chargers are more efficient, but most still have the power factor (page 10) issues that necessitate larger generators.

## Auto-start/stop

Most generators can be set up to start automatically when the battery voltage is below a preset level and then stop at a higher preset level. Facilities for doing this are usually built into the solar regulator or energy monitor, but as noted in the section on installation, setting this up *may* need specialised help.

## Generator noise

Unless silenced, diesel-power generators (in particular) are noisy beasts. Even small ones can be heard from a kilometre or more away. It is possible to quieten them to at least acceptable levels and details are included on the section on installation - see page 79. Some manufacturers make enclosed silenced units. An example is shown below right.

## Generator size

For big outback stand-alone systems there is a good case for a unit large enough to provide backup in the event of a major failure (such as a direct lightning strike on the solar modules). Also, in the event of a long period of heavy cloud, a fair-sized generator is able to supply power whilst also recharging the battery bank.

As noted re battery charging on the previous page, where relevant, allowance must be made for any major equipment with adverse power factor (page 10). This is best discussed with an electrician or the generator supplier. It may require the generator to be oversized to allow for this.

It is better to have a generator that is too large than too small - but don't go overboard re this or you'll spend money unnecessarily for fuel. They are generally most economical when running on 50%-80% full load.

## Generators and switch-mode chargers

Most switch-mode chargers are protected against spikes and other electrical nasties that can prevent them working properly, or at all, from cheap generators.

In cases where the charger will not run from your generator, redress is close to impossible. Each vendor will blame the other, not least because the generator probably will run other loads, and the charger is likely to work well from the grid supply.

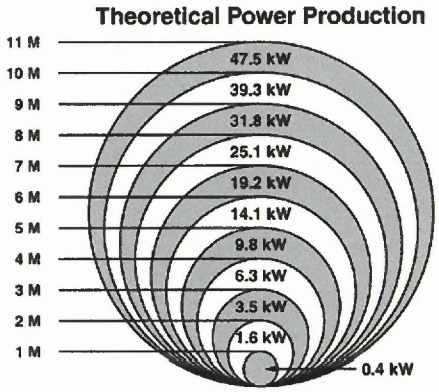
The problem usually is the generator but proving it is close to impossible. Avoid this situation up-front by buying both units from the same vendor and stressing, in writing, that each unit must work with the other.

This problem is mostly encountered with the horrible and massively polluting two-stroke $99 petrol generators that grey nomads tend to buy, but one well known and costly generator suffered from this too. It is rarely encountered with diesel generators.

*Kipor 8.5 kWh diesel generator's claimed noise level is 51 dB at 7.0 metres. Pic Kipor.*

# Alternative Power - wind & hydro

Wind power systems with propellers smaller than two to three metres are virtually useless in urban systems. This is due to an absolute physical limitation: the power they develop is a function of the square of the propeller's diameter and the cube of the wind speed. If wind speed halves, output drops to one eighth. Equally, if wind speed doubles, power increases eight times.




*This is the theoretical maximum that a wind turbine can produce. Good ones develop half to two thirds of this. Pic: Government of Ontario.*

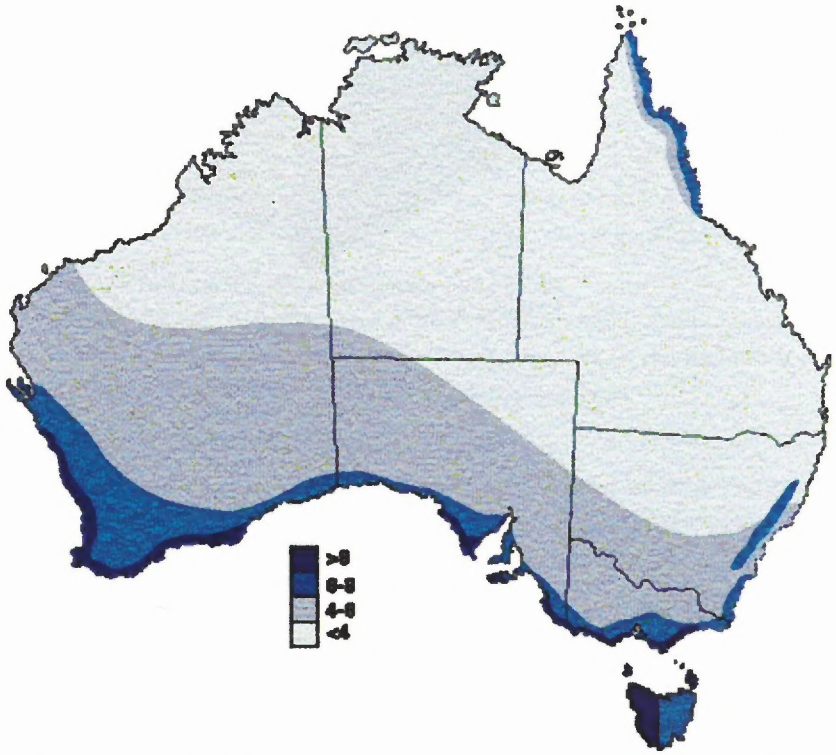
Vendor promotional material typically shows current output from wind speeds of 10 km/h, but rarely discloses that current is at too low a voltage to be of value, at least for charging. Few small wind turbines have usable output until wind speed exceeds a (rare) constant 20-25 km/h. Many produce their claimed rated output only just short of the wind speed that blows them apart.

One supplier states: 'the average wind speed needs to be above 5 m/s' (18 km/h) 'to make installing a wind turbine worthwhile'. The average yearly constant wind speed, even in the *windiest* parts of Australia (including Cape York, Albany and Geraldton) *is less than 15 km/h.* Across most of Australia it is far less.

Councils tend to be paranoid about the required high masts, and neighbours rightly object to their noise. They are hard and potentially dangerous to erect and require ongoing maintenance that's more safely done by hauling them up and down. They may require mechanical restraint or even taking down in heavy winds. On top of that, the associated industry is unregulated. In most countries related performance standards are non-existent.

## Larger units

Due to the square law involved, wind power begins to be effective with propellers of about five metres diameter and above. These are well worth considering on isolated windy properties but really need to about 35 metres above ground level.



*Typical wind speeds around Australia - in metres/second. (To convert to km/h multiply by 3.6). Reproduced by permission of the CSIRO from its valuable resource* 'Wind Resource Assessment in Australia - a Planner's Guide' *- by Coppin, Ayotte and Steggel - Oct 2003.*

At times they may develop more energy than can be used or stored in batteries, but that energy could possibly be used then for pumping water.

The bigger units need skill and experience to erect and take down.

## Micro hydro-electric

Where there is a reliable supply of water and adequate head, small hydro-electric turbines are cost effective power generators.

They pipe water from as high as possible and direct it to impinge on a water wheel (turbine) at high pressure. The turbine is usually direct coupled to an electricity generator.

Output depends on the water pressure and volume available, but for most smallish systems the former is more important. A general guide is that one needs a site that provides the greatest fall over the shortest possible distance, and for the generating mechanism to be located there. This is because it is usually cheaper to run electrical cable than water pipes over distance using the large diameter piping that is essential to limit energy losses.

## Turbine types

Different types of water turbines can be used depending on the head of water, flow rate, etc. With a water head of 50 metres or more, a traditional Pelton wheel can be used. For low head installations, Francis or propeller-type turbines are used. Where there is ample flow but little pressure, propeller-type turbines work well. One, (the Crossflow turbine), works well at heads ranging from one metre to 100 metres. Very small DIY systems can use centrifugal pumps run back to front as generators.

## Cost

A small hydro-electric plant is not expensive as long as major earth moving is not required. Experts in this field advise that the cost is typically one third that of solar energy.

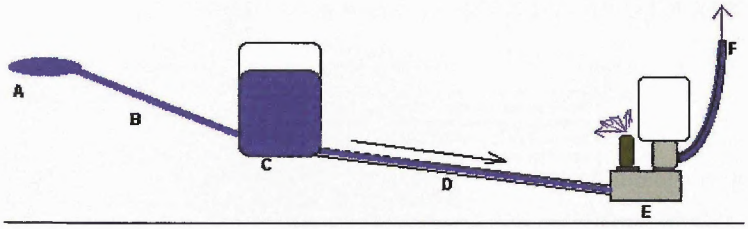
You may need to obtain 'resource consent' (for diverting part of the water flow) and its quantity and flow may be restricted. Some councils charge fees for diversion.

*This micro-hydro system built by self-taught engineer, Anastase Tabaro, provides power to households in his village. The Rwandan government installed electrical poles in the village to supply electricity to a dozen homes, including the church. Pic: European Press Agency.*

## Ram pumps

Ram pumps (described by alchemist Robert Fludd in 1618) are believed to have been used since the 1500s.

These pumps need no external source of energy other than flowing water as they exploit the principle of the 'conservation of energy'. They use the momentum of a relatively large amount of moving water to pump a relatively small amount of water uphill - to a height of 100 metres or so if required.




*How a ram pump works. Water flows from its source to a collector (C). Drive pipe (D) is about 30 metres long. Water from the collector flows through it, building up speed and hence momentum and a great deal of pressure. Once water gains maximum speed the valve (shown as gold) slams shut. The pressure causes another valve to open and the water forced at high pressure through delivery pipe (F). The whole cycle then repeats, delivering water in bursts.*

These pumps are truly basic and ultra reliable. Their downside is that only 10% or so of the waterflow through the pump is forced up the delivery pipe. The rest is lost via a (here gold coloured) release valve.

*Commercial ram pump. Pic: source unknown.*

Ram pumps are ideal for pumping up water from a free flowing stream. They are *very* noisy and need siting well away from any neighbours.

The Rainbow Power Company (Nimbin, NSW Australia) is a good source of information and equipment on ram pumps, hydro-electrics and solar generally.

See also british-hydro.org, and atlaspub@bellsouth.net.

# Fuel Cells

Fuel cells generate electricity via an electro chemical reaction between a fuel and an oxidant, not by burning it to produce heat. Some use hydrogen as fuel and oxygen as the oxidant, but more commonly and less efficiently, by producing hydrogen within the unit from LPG, natural gas, methanol, diesel, etc. Whilst some heat is generated in the electrochemical reaction/s, the cells use only a fraction of the fuel of a conventional generator doing the same work. According to the US Department of Energy, fuel cells are 40%-60% energy efficient - or more if the heat internally generated is also utilised.

Fuel cells are silent and virtually pollution-free. Excepting for a by-product emitted as a small amount of pure water, similar in content to a child's exhalation, they are virtually pollution free, and also silent.

## *Fuel cell history*

*Apollo fuel cells. Pic: the Scott Schneeweis collection, Sierra Vista, Arizona.*

The fuel cell concept originated in 1843, but there was little meaningful development until 1955 when GE's Willard Thomas used a sulphonated polystyrene ion-exchange membrane as the electrolyte.

Later, GE's Leonard Niedrach found a way of depositing platinum onto this membrane. The result was further developed by GE and NASA, and during the Gemini space project.

Pratt and Whitney improved the design to ensure longer life, and supplied about 50 fuel cells for the Apollo and Skylab projects.

Each Apollo craft had three cylindrical units - each 570 x 1120 mm and 109 kg. Each produced 560-1400 watts. The later Space Shuttle cells were 380 x 1015 mm, and 116 kg. Each produced 7-12 kW.

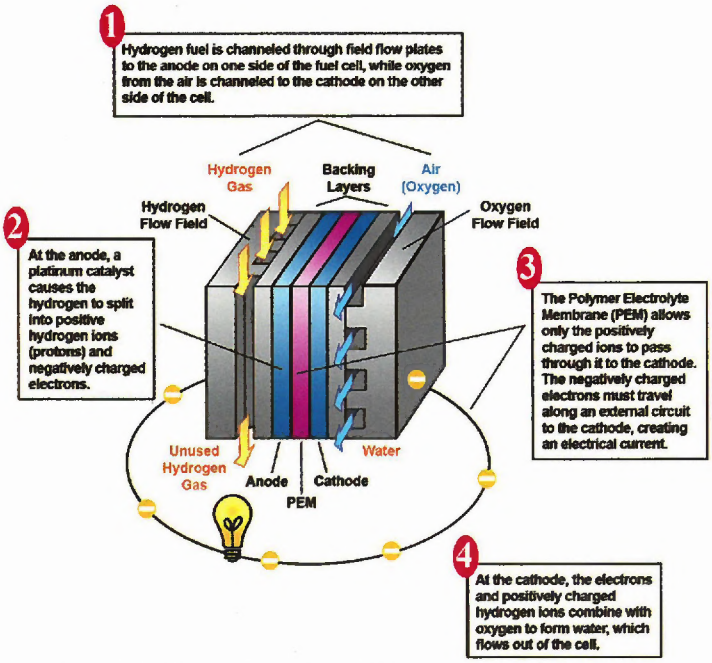
## How fuel cells work

A fuel cell module's basic operation is battery-like. Each cell produces about 0.7 volts. Cells are connected in series to produce whatever voltage required.

Hydrogen is fed to the anode plate and oxygen (from the air) to the cathode plate. The hydrogen is split into positively charged protons, and negatively charged electrons, via a platinum catalyst.

The protons are able to flow to the cathode via an internal polymer electrolyte membrane.

Electrons flow to the cathode via an external circuit - thus providing usable electrical energy. The re-united protons and electrons combine with oxygen at the cathode.




*How a typical fuel cell works. Pic: courtesy of Michegan Molecular Institute, USA.*

## Commercial development

Large scale commercial fuel cells of a typical 100 kW upward have been available since the 1980s. Work has been underway to produce small scale (0.5 kW-5.0 kW) units for many years. Some are commercially available today and are already a viable alternative to generators.

There are many different types of fuel cells. A few run on pure hydrogen and operate at relatively low temperatures. Most, however, use hydrocarbon fuels, including natural gas.

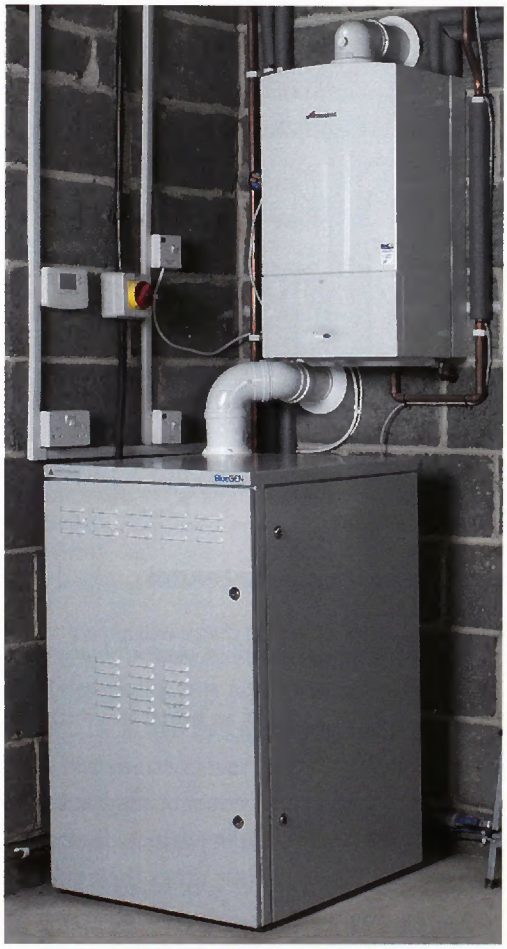
The initially promising Australian Ceramic Fuel Cells Limited (CFCL) developed the BlueGen (natural gas fuelled) unit that combined heat and power micro fuel cells to build 1.25 kW units that produced about 30 kWh/day.

A number of BlueGen units were installed in Australian offices etc where both heat and power were required - but sales were limited by there being no mandatory feed-in tariff - limiting sales (at $35,000 per unit) to those who could use all the power onsite.

The company moved to Germany in 2013 - becoming Ceramic Fuel Cells GmbH. That company became insolvent in early 2015 but was bought in July 2015 by SOLIDPower GmbH.

The new owners state that they intend to continue production of the existing unit, to reduce manufacturing costs, and to develop a 2.5 kW unit (that also has a thermal output of 2 kW).

SOLIDPower GmbH states 'it will continue the existing business' . . . and that 'for customers, suppliers and other stakeholders the familiar contacts will be available as before'.



*The Australian CSIRO inspired washing machine sized BlueGen unit fits comfortably into a corner of a garage. Pic: Ceramic Fuel Cells.*

## Summary

Fuel cell generators using natural gas increase the utilisation of existing gas networks, especially during summer when the demand for gas is low, and the demand for electricity is high.

*The BlueGen unit produces up to 35 kWh and 200 litres of hot water a day. It does this almost silently and with very low emissions. Pic: Ceramic Fuel Cells.*

This technology is developing fast, with any number of companies worldwide actively working on producing viable products for large scale production.

The global market is huge as it offers an almost pollution free source of distributed electrical power - particularly needed in third world countries.

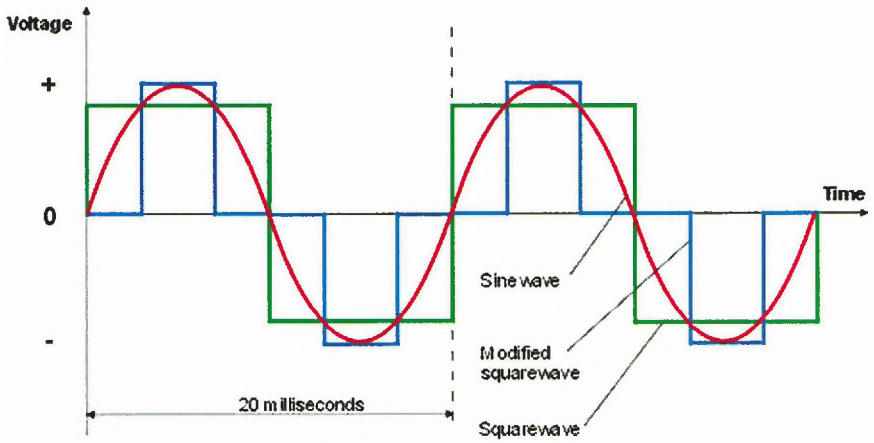
Fuel cells will inevitably become silent and clean replacements for conventional generators. It is possible that they will eventually become a viable alternative to grid-connect back-up.

The technology, however, now appears to be (partially) challenged by increasingly affordable lithium-ion based battery/ inverter backup systems that enable the time shifting of day-time solar (for later use) - see pages 58-61.

# Inverters

Inverters convert direct current from a battery (or, with grid-connect, directly from solar modules and inverter) into mains-like alternating current. There are three types of inverter: square-wave (those not already taken to the tip should be), modified square-wave, and sine-wave.

The cheaper, modified square-wave inverters may run older appliances but not necessarily appliances made recently. Some appliances, particularly laser printers, are likely to be damaged by them.




*This is how voltage and current change with respect to time with pure sine, modified square wave and square wave. Pic: original source unknown.*

Sine-wave inverters produce cleaner electricity than the grid supply, and can be relied upon to run any appliance within their rating. Only these should be considered for general home and property use.

## Silicon camels

The earlier iron-cored transformer based inverters were like silicon camels. They carried normal loads forever, accepted minor overloads for up to half an hour, and extra heavy loads for 10 to 20 seconds. They rested before restarting if seriously overloaded.

This overload capacity was useful because many electrical devices draw a lot more than their running current whilst starting. These include water pumps, fans, older battery chargers, halogen light globes, etc. Some require two to four times their running current for the first second or two after being switched on.

A typical older inverter with a 'continuous capacity' of 4000 watts provided up to twice that for a few seconds and about 6000 watts for up to 10 minutes. Their downside was cost. Efficiency too was generally poor but some later ones exceeded 90%.

The later switch-mode units are smaller, very much lighter, and cheaper per watt, but have next to no overload capacity. Some are even derated for loads exceeding a minute or two. These inverters must be selected such that they can cope with the starting current drawn by many appliances (see page 22).

Most inverters (new or old) are generally limited to about 1200 watts at 12 volts, up to 2400 watts at 24 volts, and up to 4800 watts at 48 volts. Some inverters can be paralleled. Twinned 2400 watt units can thus supply up to 4800 watts. This mode of configuration also ensures that if one fails the other's output is still available.

## Stand-alone inverters

The simplest are stand-alone units. These have power outlet sockets, usually on their front panel, and 230 volt appliances plug directly into those outlet sockets.

To install, all that is needed is to run the usually supplied leads to the associated battery.

*Inverters, such as this Projecta unit, that have power outlet sockets built into the actual unit can legally be self-installed but must not be connected to any fixed wiring. Pic: Projecta.*

They absolutely must not be connected into fixed mains wiring. They are made in both 12 and 24 volt form, but most are limited to supplying around 500 watts.

## Inverters for fixed wiring

Inverters intended for permanent installation have no inbuilt outlet sockets. They must be connected into 230 volt electrical system wiring by a licensed electrician, and following the mandatory conditions of (in Australia and NZ) AS/NZS 3000:2007 as amended in 2012.

These inverters are made in various sizes. Some modular units, as shown (right), can be paralleled to provide larger capacity, or three-phase 415 volt output. Not all can do this so, if that may be needed in the future, check the capability before buying.

*Four paralleled Outback Power inverters provide 14.4 kW at 48 volts. Pic: Jordan Solar (USA).*

## Grid-connect inverters

Grid-connect inverters operate in a similar manner as conventional inverters, excepting that, much as a surfer synchronises with a wave, the inverter's alternating current output must synchronise with that of the electricity grid. This is ensured within the inverter.

All grid-connect inverters must be tested to AS3100, or the IEC equivalent, and be certified for suitability by a state regulator.

## Battery backed grid-connect

To protect electricity workers, grid-connect systems *must* include a 'break before make' relay that automatically isolates the output to and from the grid in the event of the grid supply failing, or being shut down. With most systems this leaves the user without power. A few 'critical use' systems have battery back-up that, when needed, isolates the solar system from the grid supply, and uses an inverter to supply 230 volts. This can be done by specifying a specialised inverter at the time of the original installation, or via a separate inverter and charger (or an inverter with an inbuilt charging function), and an associated battery bank.

As noted in the Preface to this edition, and also on pages 58-61, battery back-up is likely to become an integral part of many new grid connect systems (and retrofitted to existing systems) such that excess input currently sold to the electricity supplier supplies the home's needs during peak supply periods.

This will also benefit grid-connect users who are away from home during the day.

One existing example is the Victron Energy MultiPlus range of inverter/chargers that combine a sine-wave inverter, battery charger, and high speed power transfer in the one unit. Several such units can be paralleled for increased inverter and charger output and multiple units can be connected together to provide three-phase power.

Selectronic's SP PRO similar units provide 2.5 kW and 3.5 kW (24 volts) and 4 kW and 6 kW (48 volts). They are unusual in being rated at 40° C ambient temperature rather than the industry common 25° C. This is important in hot areas as an inverter's output is reduced considerably as it warms up. See pages 58-61 re the above.

*This Victron 24 volt inverter/charger provides 230 volts at 3 kW, and 6 kW surge capacity, and up to 70 amps for charging a 24 volt battery bank. Pic: Victron.*

# Energy Audit

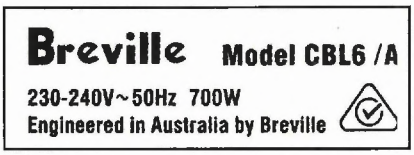
An energy audit takes stock of all your electrical lights and appliances, establishes how much energy each draws and for how long, on average, each is likely to be used per day. It highlights unexpected areas of waste and enables a comparison with known national averages, and the generally lower usage of existing solar users.

*The Belkin Conserve Insight shows watts and also cost per kWh. Basic but accurate, it is really all that is required. Pic: Belkin.*

It is easy to do this yourself by using an energy meter. Be wary of ultra cheap ones: as *Choice* magazine (July 2011) noted, many mislead when measuring low wattage loads.

## Existing usage

Following the example below, list everything electrical you intend to use. For each, note the amount of energy the item consumes. This is usually embossed on that item or printed on an attached panel (right). It is also usually included in makers' specifications.




*Most electrical devices have a label such as this that quotes energy usage (in watts).*

Consumption is usually shown in watts, but there are a few traps. Electric motors and microwave ovens may indicate wattage but as a measure of work done, not the energy expended in doing so. Pump motors may show $P_2$, (i.e. the power the motor develops), and/or $P_1$ (i.e. the power the motor actually draws on full load). Ideally use that $P_1$ data.

If wattage only is shown it is odds on that this is $P_2$ (power developed). If so adding 50% to that $P_2$ figure, whilst not exact, is usually close enough.

If it is not feasible to establish the consumption, use the mid-range (where applicable) of whatever is shown in the list on page 53. This too is not exact but errors usually more or less cancel out. Assess how long each device is likely to be used. Use probabilities, not rare exceptions.

Multiply each device's energy draw in watts by the probable hours used each day. The result is the energy draw in watt hours per day. The answer is likely to be in the thousands. It is more convenient to show this as 12.5 kWh/day, rather than 12,500 watt hours per day.

Compare what you come up with against the examples on pages 82-87. Each describes an actual installation and the often dramatic reductions in energy draw achievable by minor and affordable changes.

As a benchmark, the average energy draw of a three bedroom grid-connected (but non-solar) urban home is (in 2013) about 17.5 kWh/day.

There are no official figures for stand-alone solar installations but anecdotal evidence suggests it is less than that of grid-connected homes, not least because their owners become more concious of unneeded lights and TVs, etc. that are left on all day.

Once accustomed to using solar power one tends to be horrified by the energy wasted by most users, especially companies, who rely on grid power.

| Item | Watts | Hours per day | Watt-hours/ day |
|---|---|---|---|
| TV | 200 | 2.5 | 500 |
| DVD | 30 | 1 | 30 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Total | | | |

| ITEM | Consumption (in watts) |
|---|---|
| **Air conditioners (2.5 kW)** | 600-1000 Most prior to 2004 draw at least 750 watts – see pages 16-17 |
| **Blankets** | 60-120 |
| **Blenders** | 400 |
| **Breadmakers (per loaf)** | 350-450 |
| **Can openers** | 100 |
| **Clippers** | 35 |
| **Clothes dryers** | 1000-2500 |
| **Coffee grinders** | 75 |
| **Coffee percolators** | 500-600 |
| **Computers – desktop** | 400-500 |
| **– laptop** | 70-100 |
| **Computer printers – bubble jet** | 120 |
| **– laser** | 900-1000 |
| **Dishwashers** | 1000-3000 |
| **Fans (small)** | 30-40 |
| **– pedestal** | 75 |
| **– overhead** | 100-150 |
| **Fax machine (standby)** | 15 |
| **– printing (thermal)** | 100-150 |
| **– printing (laser)** | 1000 |
| **Food processors** | 450-550 |
| **Frying pan – electric** | 1200-2200 |
| **Fridges*** | 100-250 (See examples on page 13) |
| **Hair dryers** | 500-1250 |
| **Infra-red grills** | 1500-2000 |
| **Irons** | 1200-2200 |
| **Juicers** | 350-450 |
| **Kettles/jugs** | 2200 |
| **Lights** | |
| **– halogen (typical)** | 10-50 |
| **– compact fluorescent (typical)** | 5-22 |
| **– white LEDs** | 3-12 (extra-low voltage) |
| **Microwave ovens (800 watt) – normal** | 1350 |
| **– convection** | 1800 |
| **Ovens** | 2500-5000 |
| **Radios** | 15-20 |
| **Televisions – 60 cm** | 18-50 (a few draw up to 75 watts) |
| **– 80** | 40-60 (a few draw up to 100 watts) |
| **– 100** | 40-110 (a few draw up to 150 watts) |
| **– 120** | 60<br>0-130 (a few draw up to 170 watts) |
| **– 140** | 75-175 ( a few draw up to 250 watts) |
| **Space heaters** | 1500-2000 |
| **Vacuum cleaners** | 750-1500 |
| **Washing machines** | 200-600 |
| **Waste disposal units** | 500-750 |
| **Water pumps – 12-24 volt dc** | 50-100 |
| **– 230 volt ac** | >750 |
| | See page 22 for power tools, etc. |

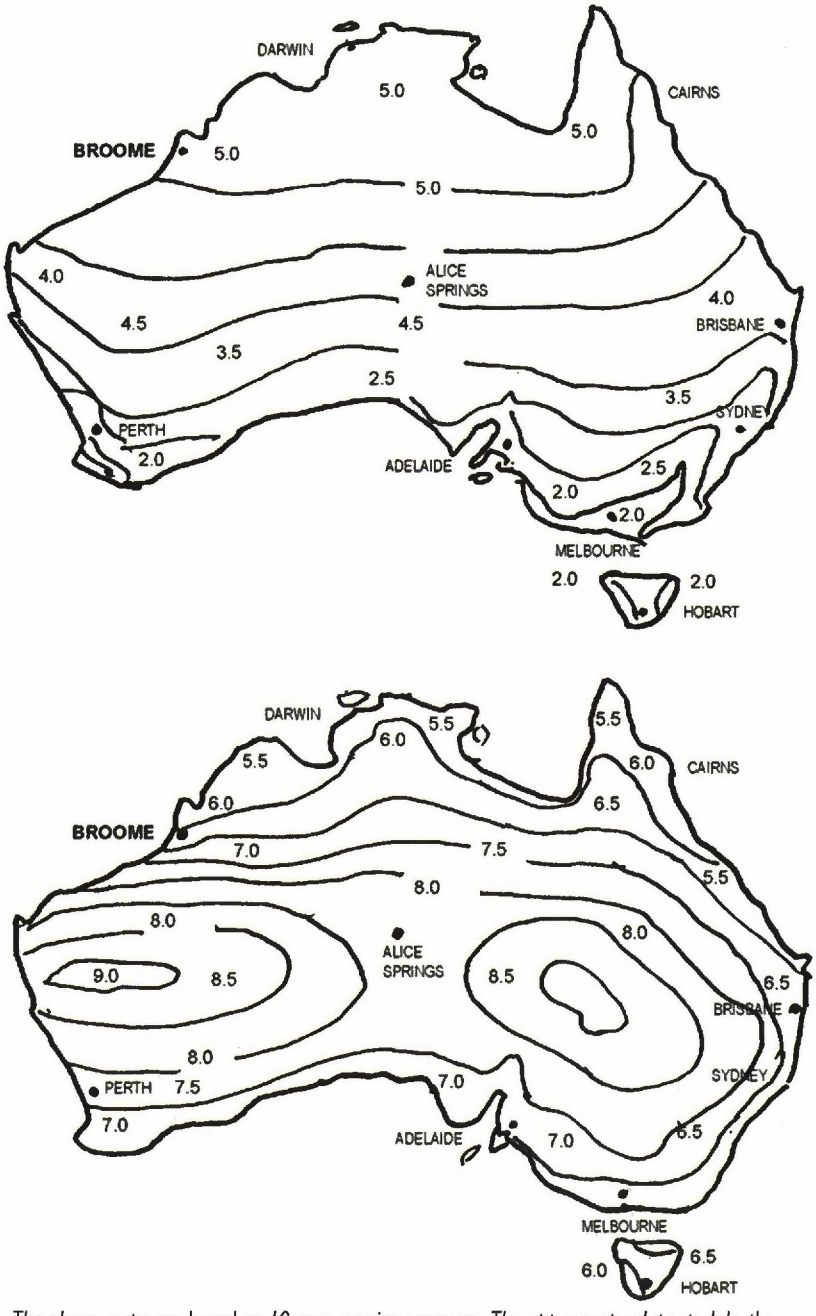
** Fridges constantly cycle on and off. The energy draw shown relates to the 'on' cycle and is affected by the thermostat setting, ambient temperature, installation, usage pattern, etc. On/off ratios may vary from eight hours on-time a day – to continuous.*

# Scaling Stand-alone Systems

This chapter shows how to assess various sizes and capacities to ensure the resultant system is adequately and proportionately scaled. Some of the content is already covered, but is condensed here for ease of use.

As outlined in the previous two pages, note the amount of energy each appliance uses, and check against the specialised coverage in earlier sections of this book.

Look particularly for any item that draws a great deal of power but is used only briefly and then rarely, such as an arc welder or big air compressor. These are better run from a generator as it makes no sense to grossly oversize any costly part of the system to cope with high rare usage. Study your energy audit carefully. Rework it if necessary and compare it against the systems on pages 82-87.




*The above maps are based on 10-year running averages. The upper map relates to July, the lower map to January. To use, multiply your nominal total solar wattage by the PSH shown for your area. Your usable wattage is about 70% of that amount. These maps are based on Australian Bureau of Meteorology data.*

When you have finished the above, it pays to implement most or all energy saving changes before you go any further.

## Available irradiation

Using the solar maps shown here, check your summer and winter irradiation. Most places have a more or less smooth change between the seasons but this cannot be assumed: some areas do not. Solar charts for almost anywhere can be obtained from meteorology bureaus.

For most locations, average data is accurate but there may be substantial daily variations.

Note the relevant Peak Sun Hours (PSH) and multiply that by 70% of the solar modules' nominal capacity in watts (i.e. of that seemingly claimed) to give the total watt hours you are likely to average each day.

Brisbane, in July, has about 6.5 PSH. With one nominal 100 watt solar module the probable daily input is thus 70 watts times 6.5 PSH (455 watt hours).

For stand-alone systems never skimp on solar capacity. If you must compromise, reduce battery capacity. Like money, if you do not have it, it is not there to store.

## Needed solar capacity

A minimum yearly average of 2.5 to 3 PSH enables solar to be *economically* viable. Where you have that, adding 25% more solar capacity than you need for normal daily use (and cutting back on non-essential usage) will get you through periods of less than usual sun without breaking the bank. As a very rough guide it is realistic economically to scale the system to provide 95%-97% from solar alone (except in the Melbourne area - where 85%-90% is a good target).

Assuming rebates still apply (for stand-alone systems), legislation may set the upper capacity limits: otherwise for stand-alone systems the solar capacity required relates to what extent you wish to use generator back-up, e.g. when solar input is low (as in a Tasmanian or New Zealand winter). The decision may be influenced by environmental as well as monetary considerations, but it is advisable to have an alternative source of power to cope with long periods of little or no sun.

It's worth doing a few sums to work out the relative costs of adding more solar, or spending ongoing money on increasingly costly fuel, but the balance is inexorably shifting in favour of more solar, not least because solar module cost fell 75% or so in price from 2010-2014.

## Solar regulators

The solar regulator ensures that the output from solar modules is acceptable for the rest of the system. The more basic regulators are inherently unable to do this efficiently. A so-called power mismatch precludes them accessing some of the otherwise available energy. This mismatch is due to nominally 12 volt modules producing peak power at about 17 volts, but batteries require charging from 13.2-14.7 volts. That energy between 17 volts and 13.2-14.7 volts cannot be utilised by basic regulators.

Some of the otherwise unaccessible energy can, however, be made accessible by the MPPT (Multiple Power Point Tracking) technology (page 39) now common in most up-market stand-alone system regulators and all grid-connect systems. The technique is especially worthwhile for stand-alone systems where the solar array is distant from the batteries. It enables the array to run at higher voltage, yet still charge at 12, 24, or 48 volts. This permits substantially smaller, and correspondingly cheaper, cable.

Not all users (nor installers) realise that up-market solar regulators are limited by *current:* (not wattage or voltage). A 60 amp regulator will thus handle 720 watts at 12 volts, 1440 watts at 24 volts, or 2880 watts at 48 volts. The higher the voltage at which they can be run, the cheaper they are per watt. Some MPPT units accept 300 volts plus.

Once the solar array voltage has been decided, the required size regulator is the solar array's maximum current in amps, plus about 20% to cater for sunny days with low scattered cloud that may momentarily increase solar output. As noted previously, this often occurs briefly in areas close to a large expanse of water, or light coloured sand. There, sunlight from a gap in the clouds is reflected upward from the water or sand and reflected down again from the underside of the scattered white clouds. The modules thus receive both direct and reflected input.

As an example of sizing, a *true* 1.5 kw (1500 watt) array running at a nominal 48 volts generates 31.25 amps. Forty amps is likely to be the closest size regulator available. This also provides the required 20% or so excess capacity. Do not be concerned if the unit is not *quite* large enough - the rare excess current will be blocked (and thus lost) but it will not damage the regulator.

Do not confuse solar array voltage with storage battery voltage. Except for really big systems, battery voltage will be 12, 24 or 48 volts depending mainly on the size of the inverter (typically 12 volts up to 1200 watts, 24 volts up to 2400 watts and 48 volts up to 4800 watts). Above that, it is usual to have two or more paralleled inverters running at 48 volts. The array voltage can be as high as the solar regulator allows - but if above 120 volts dc (off load) that part of the system must be installed and connected by a licensed electrician. This limits self-installed systems to nominally 72 volts solar arrays as they exceed 110 volts or more off load.

## Energy monitors

Most known brand solar regulators intended for home and property systems are well made and reliable. Apart from current handling capacity, they vary mainly in the monitoring functions provided. Such monitoring is essential but ease of interpreting the read-out varies. Energy monitoring is likely to be included as part of

the solar regulator, or as a small panel that can be remotely located - ideally within the house.

Easy to use monitoring really is needed. For most systems it is hard to go past the Xantrex Energy Monitor. It is also marketed under other brand names. Whilst the unit may at first appear to offer too little for too high a price, long-term acquaintance proves otherwise. It is perfect for quick checks, yet offers a lot more for those delving into its less obvious functions. Another good buy is the Powertech unit from Jaycar.

*This is one of the two 1800 amp hour battery banks at Yarrie Homestead (main pic next page). Pic: Peter Wright.*

## Battery capacity

As a rough guide, battery capacity is needed from an hour or so before nightfall until just after dawn. In supplying this, the battery bank should ideally discharge by no more than 10%. It ideally needs to fully recharge by the following midday.

Depending also on daytime draw, and how much solar keeps coming in, this also comfortably copes with three or so days of zero sun, or a week or so of partial sun, without discharging batteries below a damaging level.

For most home and property applications battery capacity needs to be six to 10 times the average night-time draw in watts but, as battery makers think in amps and amp hours, you'll need to juggle the numbers. Dividing watt hours by the battery bank's voltage gives the equivalent in amp hours. With a 48-volt system, an overnight draw of 3.5 kWh is thus 73 amp hours.

A suitable battery bank could be 700 amp hours but, as solar costs have fallen dramatically and battery costs have risen, it now pays to have more solar capacity and less battery capacity. The extra solar will provide more input during long overcast periods (it only rarely drops to zero).

Never have excess battery capacity - if the solar energy is not there - it is not there to store. Associated batteries will never fully charge. This shortens their life and increases energy loss.

## Battery chargers

The charger must be suitable for charging the type of battery used, and big enough to bring a deeply discharged battery bank up to full charge within 10 or so hours. No high quality high capacity charger is cheap but this task absolutely necessitates top quality or you may save a few hundred dollars and wreck a multi-thousand dollar battery bank.

Traditional battery chargers (that have transformers) are ultra-reliable, but massively heavy and only 60%-70% efficient. Their output varies in proportion to input voltage - and that, from most generators, is far from stable.

The more recent switch-mode (transformer-less) chargers are a fraction of the weight and, at a typical 90% plus, are much more energy-efficient.

To assess the charging capacity required, divide the battery bank's capacity by about ten. A 500 amp hour battery thus requires a 50 amp or so charger. The likely cost will be 15%-20% of the price of the batteries.

## Generators for battery charging

A generator's minimum size may be determined by various factors but in most cases it will be a function of that required by the battery charger plus any other loads that *have* to be powered at the same time. It is necessary to allow for the extra current drawn by electric motors, conventional battery chargers, etc. for the first second or two whilst starting. This is often a limitation of petrol engined generators smaller than 3 kW to 4 kW. Those above that size (and most diesel units) can usually cope.

Big mobile air compressors are a special case. Most start up on full load and may thus need up to 10 times their running current to get them going. Their most common outback usage is for blowing out silted bores, and compressors capable of doing that draw a great deal of power. Most people rent self-powered units for the few hours required - rather than scaling the system to supply the rare need. They are usually trailer-mounted and driven by a directly-coupled diesel. The same applies to big arc welders, etc.

Conventional battery chargers are typically only 65%-70% efficient and have a power factor (page 10) of about 0.7. If you have this type of charger, the generator's kVA rating will need to be at least twice that of the battery charger's output in watts.

With the far more efficient switch-mode battery chargers mentioned above, the generator needs to have a continuous rated output of only 40% or so more than the switch-mode charger's output in watts. Before buying, however, advise the vendor that the switch-mode charger is to be generator-driven as some owners report that such chargers prematurely failed and warranty was refused due to the generator input.

Before deciding, check how close the proposed generator size is to the home or property's normal running load. It is possible to provide *total* backup in the event of a major solar failure (such as a direct lightning strike on the modules), but it is cheaper initially (and with ongoing fuel costs) to postpone running high current appliances like the washing machine, dishwasher, etc, and to scale the generator to supply limited domestic power whilst also able to recharge the battery bank - albeit at a slower rate.

## Fuel cells

Eventually, fuel cell technology (pages 48-49) will replace generators for solar back up, probably with an AGM or lithium-ion battery bank to cater for short term peak loads. The 35 kWh/day natural gas powered BlueGen units described on page 49 are already practicable for big property systems and communities. These are now made in Germany. The 2013 price was about A$35,000 but the current (2015) price is not yet known. Details will be posted on our website: successfulsolarbooks.com when information is available.

*This 11 kW system provides power for Yarrie Homestead (Marble Bar, WA). The entire output is handled by four Outback Power 60 amps regulators. Pic: Peter Wright 2008.*

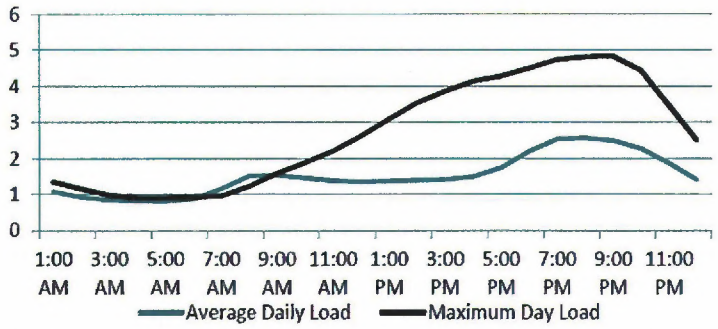
# Grid-connect & Tariff Changes

Grid-connect theoretically combines solar input with convenient grid power. Excess solar is paid for by the electricity supplier, deficit is drawn from the grid. The concept appeals for varying reasons: environmental consciousness, distributed electricity generation, less dependence on 'big brother', etc. Initially, Australia offered extremely high feed-in rebates - even paying for energy owner *consumed*, as well as fed into the grid. Some feed-in contracts assured owners of 44-60 cents per kWh until 2028.

The very high feed-in payments resulted in a major monetary inequity: they were paid by electricity suppliers who covered the cost by raising electricity prices for all (most of whom were/are non-solar users). The amounts paid became so high that state authorities progressively reduced them between 2011-2012, after which new users were paid what rapidly became 5-6 cents kWh. From 2010 to 2028 feed-in tariffs and various subsidies will have benefitted solar owners, at the expense of non-solar users, by about $14 billion.

## The grid network

The most populated areas of Australia have electricity supplied by a few but huge 'base line' power stations that are interconnected by one grid that supplies eastern states, and another for the southern part of Western Australia. These are 'natural monopolies' with their prices controlled (in eastern states) by the Australian Energy Regulator, (and in WA) by the Economic Regulation Authority.




*Whilst based on financial year 2010 (Sydney) data, this AGL graph shows the huge difference between the average day load and (dark blue) the highest maximum peak demand that year. Pic: AGL.*

Suppliers and regulators agree on electricity pricing for five year periods - taking into account the cost of electricity supply plus that of possible expansion to meet future peak demand.

Peak demand is typically 3 pm to 9 pm, with rare maximum peak demands (typically for an hour or so), on hot summer days when millions returning home from work turn on air conditioners. The grid network, however, must be scaled such that it can supply that rare demand. If it cannot it will shut down to protect itself.

Despite our expanding population, except for Queensland where both average and peak usage has risen, Australia's average electricity usage increased considerably from 2000, peaked between 2006 and 2008, and then progressively fell to (now) year 2000 levels. This is primarily due to the increasing efficiency of electrical appliances and lighting (plus a minor but growing effect from solar).

But whilst average demand is now lower, the peak demand is not falling at a similar rate. As a result our generating network is currently much larger than needed during off-peak periods, but needs capacity to cope with the peak loading. The electricity generating industry retains profitability by increasing charges: in Queensland by over 85%, (in real terms) since 2007.

A further issue is that base-line generators have no short term 'volume control'. They cannot vary power to cope with short term demand variations. Nor have they any way of storing excess power. They must be run such there is surplus power much of the time or totally shut down if little is needed.

Less populated areas (with local networks) are not so affected: they are progressively moving to multiple smaller output gas and/or diesel powered units. As demand varies, the number of units required is increased or decreased, as is the output of each.

In South Australia about 44% of electricity is generated this way. Some towns in Western Australia are doing likewise. Local distribution is via lower voltage networks owned by electricity retailers. They buy electrical energy on a virtual spot market financial basis from competing generators.

## Solar feed-in

Where solar is viable year-round, about 80% of a typical day's solar input is from 10 am to 2 pm. Peak demand (in terms of current pricing) for grid electricity, however, is 2 pm to 10 pm (reality is closer to 3 pm to 9 pm).

This does not matter for owners of modest solar grid-connect systems who use most or all of their solar generated power during the day as it does not affect the network. The many systems installed to obtain high feed-in payments, however, can only feed in at times when the grid network has ample capacity. Here, solar's inherently fluctuating nature in many areas causes local electricity distribution problems.

As a result of the above, solar feed-in (as it is now) is of only partial benefit to electricity distributors - who must pay and (for some users) massively overpay for it regardless.

## A new strategy

The major issues are thus the current need for a network (that whilst now larger than needed) must cope for rare peak loads, and excess solar input that can only be currently fed in to the network when least needed.

This is about to addressed by major changes aimed particularly at reducing peak demand. By so doing, this will enable the base-line stations to operate at lower levels. It will be done by a major change to electricity pricing, and by 'encouraging' domestic and business users to install battery capacity (charged by solar and/or non-peak grid power) for use during peak periods - i.e. by time-shifting electricity supply and demand.

## Demand charging

Currently, charging methods vary from state to state, and supplier to supplier. They are also restricted by the type of electricity meter used. Many restrict billing to a fixed delivery charge plus the quantity of electricity used. Others allow for various price rates depending on time of use, etc.

An all-but certain change will be to retain the existing fixed delivery charge, and the (possibly lower) quantity-used charge, and add a new and higher 'peak demand' charge. The latter may be based on the maximum (say 30 minute) amount drawn each on peak period weekdays, or based on the average maximum demand for similar properties in the area. This charge may vary from month to month - or seasonally.

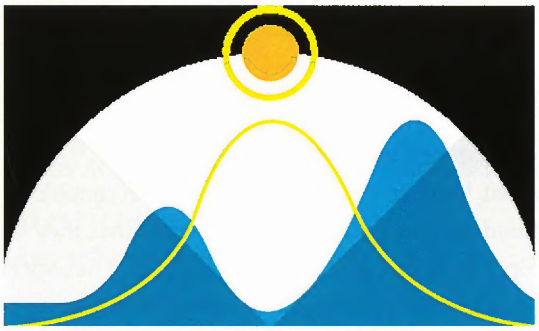
The aim is thus to change usage patterns - e.g. such as high energy draw loads becoming programmed sequentially.

## Time-shifting

The second and complementary approach affects all users. This will in effect progressively add a 'battery-like' characteristic to the supply network.

The network has substantial spare capacity between 10 pm and 7 am, but whilst it is not practicably feasible to install vast battery capacity within the grid network, it is totally feasible for it be provided within homes and businesses.

Time-shifting enables battery charging during early morning non-peak hours, and the so-stored energy made automatically available during peak hours.



**Morning demand Peak solar Evening demand**
*(adapted from a pic by Tesla USA).*

This is no speculation: system and electricity suppliers are already promoting this concept - but many with a verve matched only (in my experience in December 2015) by an inability or unwillingness to disclose even basic details of that seemingly offered. The various ways of doing this are briefly explained on page 61.

## Strategies to consider

Regardless of grid power only, solar grid-connect, or stand-alone solar (or other alternative energy), by simply following the advice and examples in this book, you can readily reduce the energy usage (particularly peak demand usage) of what you have right now. For almost all existing non-optimised systems, energy usage can typically be slashed by 30%-50% - sometimes even more.

## Non-solar grid users

Follow the general advice in this book, but if your peak demand loading is high (and cannot be avoided), the battery time-shifting approach described above may prove worthwhile.

As this assists electricity suppliers and generators to reduce peak loading, financial incentive is possible. It may thus well be worth delaying any decision until more is known. Updates re this will be posted on successfulsolarbooks.com from time to time.

## Considering grid-connect

With new user pay-in tariffs as they are, it is best to limit solar capacity to that used as it is captured. That for the average home in the sunnier parts of Australia is unlikely to exceed 2.4 kW.

This can be assisted by programming dishwashers and washing machines, etc. to operate sequentially only during peak solar input. Also, attempt to reduce peak demand usage. If this is not feasible consider supplementing the system by eventually adding the battery time shifting approach noted above.

## Existing solar grid-connect

Forthcoming changes are likely to least affect those with systems sized such that most of the solar input is self-used during the day. As tariffs are likely to be reduced to barely nominal, that fed in is virtually worthless financially. If peak demand is high it may well be worth looking at the battery/inverter time-shifting system described above, but not to increase solar input right now.

The major impact of the forthcoming changes will be felt by those with solar systems that generate far more energy than they use. Those on long term high return feed-in contracts are in silicon heaven. Those with large systems who are not on such contracts are likely to be encouraged to install battery/inverter systems enabling excess energy to be battery stored on site and used during the 3 pm to 10 pm peak. There is also a case for having sufficient energy storage to cope with the typical three to four hour electrical outages.

Several companies already offer packages that can be added to existing grid-connect systems (page 61), but here again there is a case for seeing if there is to be any incentive offered to do so.

Another possible approach is one that we are personally contemplating. Our own system, in a gas heated Sydney house that has high thermal mass, produces about 6.5 kWh/day excess energy system much of the year around, apart from mid-winter when there is still 2-3 kWh/day. The plan is to tilt the solar panels to optimise *winter* input and use that to power two ultra-high efficiency 230 volt reverse cycle air conditioners used as heaters. As these are several times more efficient than the now (increasingly costly) gas, we will use that heating during the day and rely on the home's thermal mass to retain heat after dark.

## Re-orienting solar arrays

It has been seriously suggested that in suitable geographic areas, solar arrays with considerably excess energy (feed-in) energy be re-oriented such that they face west. This reduces daily input - but provides useful grid input later in the day - assisting the grid network cope with early peak demand. Just how that could be implemented is currently not clear, but feed-in tariffs would need to be substantially re-thought.

## Going off-grid

Increasingly, some people on solar grid-connnect seek to go totally off-grid. This is not economic at present, due primarily to the cost of battery capacity. It also depends on the amount of solar input available and substantially by the feasibility of using generator back-up. At best, however, it cannot be done for anything like the cost of a current grid system - let alone one optimised via the forthcoming time-shifting initiatives. There is also a minor risk that, as in some parts of Victoria (with mains water) they become legally obliged to pay an electrical 'access' charge whether it is used or not.

Space too is needed. The average three-bedroom home requires a 7.5 kW system. This, in most parts of Australia needs 70-75 $m^2$ of north facing roof space with day-long sun access and solar panels tilted to optimise input for the proposed seasonal usage. That plus about 40 kWh battery storage will typically cope 345-350 days a year. The remaining few days can be covered by a generator that recharges the battery bank.

Cost rapidly escalates out of all proportion to increasing reliance on solar. For the above home, accepting about 12 hours a year without power requires about 15 kW of solar and 80-90 kWh battery capacity.

Seeking about six hours without power virtually doubles that. Battery costs are already falling, but even if halved, it makes no monetary sense to go off grid unless/until grid power exceeds about $1.30 per kWh. But with the planned changes this is unlikely to happen for many years - apart from rare peak demand-pricing.

Except in country areas where a grid supply is not available (or access charges are excesssive) it makes more monetary sense to use a battery time-shift system and to retain the grid to supply power during the low tariff rate periods. The above may change also if/when clean and silent fuel cell technology becomes affordable. The associated industry has (since 2005) however claimed this with ongoing variations of 'real soon now' - so such usage is not wise to forecast.

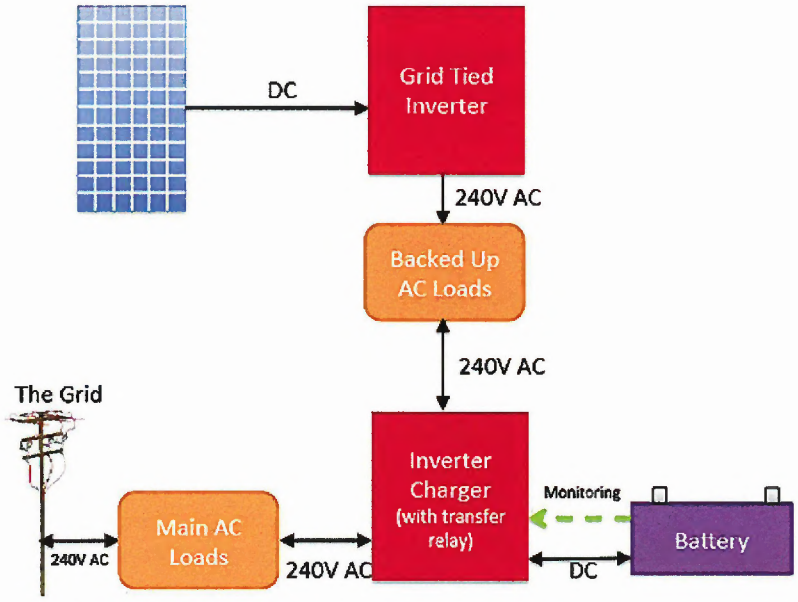
## Battery back-up technology

There are various ways of adding battery capacity - all with respective virtues and vices and also on whether it is for a new grid-connect system (of which a few allow battery back-up), or existing ones that typically do not.

It is probable that most will use lithium-ion batteries (probably LiFePO4s). These have a number of advantages over traditional batteries including the ability to deliver and accept massively higher current. Tesla's mid 2015 release of lithium-ion battery packs generated local media frenzy but most local commentators overlooked that its probable local cost *to suppliers* will be a likely A$1000 plus per 1 kWh.

The simplest (and one Tesla unit seems suitable) has the battery bank inserted between the solar array and the grid-connect inverter - and feeds that inverter when there's no solar input. Whilst efficient, simple and relatively cheap it cannot operate if the grid network goes down. Nor can it handle multiple solar panels with individual so-called MPPT operation (that eases shadowing loss). More complex forms of the above are available but usually suitable only for new installations.

The so-called 'ac coupled' approach is simple and more efficient when directly feeding the premises' 230 volt loads. When the solar input exceeds such loads, the excess energy charges the battery bank (typically 12-120 volts). It is a simple solution for time-shifting excess daytime solar for use during peak periods. The approach can also be used also for similarly time-shifting off-peak grid power.




*Typical ac-coupled system battery-back up system. Pic: solarquotes.com*

A further approach (that I have experimented with) is a portable rack (with a solar input) containing a stand-alone inverter/charger *with the outlet inbuilt* and a couple of lithium-ion batteries. This is readily assembled by those with the necessary expertise - and such units are also available commercially. The portability is a bonus for those renting premises.

As this technology changes rapidly, more complete descriptions of the various approaches will be posted from time to time on our associated website: successfulsolarbooks.com

## Probable scheduling

The restructuring noted above been discussed since 2013 or so. How it is to be done will be officially revealed during 2016. The initial changes are likely to be those tariff-related. They will begin to be introduced in 2017 and progressively implemented over the following five or so years. They are likely to vary from state to state.

## References

The major references drawn on for this section of the book are on page 100.

# Installing the Bits – legal stuff

Legally, electrical voltages in Australia and New Zealand are now defined as below. Other countries use the same terminology to describe different voltage ranges.

## Extra-low voltage

Within Australia and New Zealand, AS/NZS 3000:2007 as Amended 2012 defines Extra-low voltage as:

Alternating current – not exceeding 50 volts.

Direct current – less than 120 volts ripple-free.

There are further related forms of such voltage - (such as Separated Extra-low voltage) but they are not relevant in a solar context.

## Low voltage

Again as defined in AS/NZS 3000:20007 as Amended 2012, Low voltage begins where Extra-low voltage ends. In Australia and New Zealand it is from 50 volts ac to 1000 volts ac and from ripple-free 120 volts dc to 1500 volts dc. In Europe, Low voltage (dc) is defined as 75 volts to 1500 volts.

The USA has so many definitions of its 110 and 220 volts ac that one can only wonder how its electricians know which applies to what.

## Who may do what

In 2001, the then new joint Australian/New Zealand Standard AS/NZS 3000:2000 (often called the *Wiring Rules*) changed the emphasis from the previous rigidly prescriptive, and towards work practices proven historically and technically to be safe. It also placed final responsibility directly onto the licensed electricians and contractors who did the work. Since then, Australian electrocution fatalities have halved.

The latest version of the Standard (AS/NZS 3000:2007 as Amended in 2012) extends the above philosophy and practice. This latest Standard is also less complex to follow - but is still far from simple.

Within Australia, who may or may not do what is still rigidly defined by state and territory jurisdictions. In all states and jurisdictions, anyone who knows how to can install and/or work on Extra-low voltage wiring.

Who may or may not work with Low voltage, etc. is covered under state work practices and safety legislation. This varies from state to state (particularly in Victoria for caravans and motor homes) and defines the work that only licensed electricians can do. This applies regardless of whether the source of the power is from the mains, a generator, or via an inverter intended for connection into fixed wiring.

## New Zealand and elsewhere

In New Zealand, anyone who so wishes may legally do (defined) home and RV wiring, subject to the work being subsequently passed by someone appropriately certified. Details are in the New Zealand Electricity Act 1992, sections 110 and 111. Also invaluable is NZ ECP 51:2004 (NZ Code of Practice for Homeowner/ Occupier Electrical Wiring in Domestic Installations).

Who can do what varies from country to country, and from time to time. Few countries have restrictions as rigid as Australia's. Readers are advised to check the current situation for their area themselves.

# Safety Precautions

To electricity, one's body is a poorly insulated skin bag containing electrolytes and a network that carries oxygen, dissolved in blood, to the muscles and the brain. That network conducts electricity only too well. Whilst causatively related, the risk is not voltage as such but the amount of current that flows and, particularly, how and where it flows. Current across the fingers of one hand is relatively harmless. Minor current passing through the brain or heart, however, can be fatal, especially if sustained. Wet skin and especially minor hand wounds seriously increases current flow, and the attendant risk.

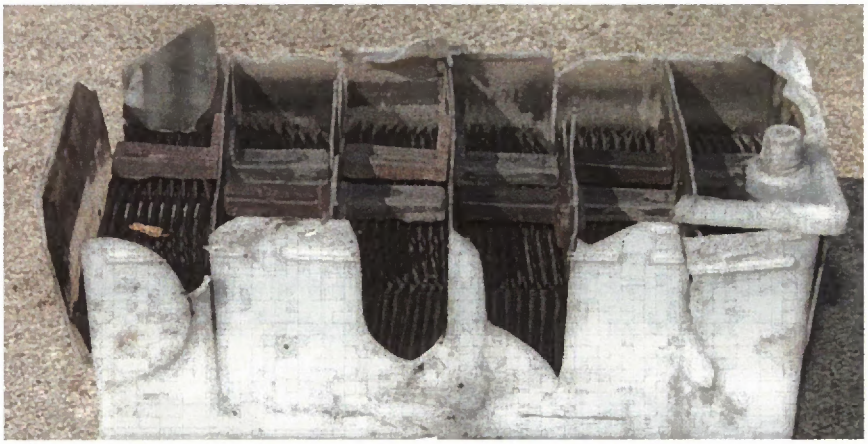
Alternating current is generally more dangerous than dc as it causes severe muscular contractions and the heart to fibrillate (quiver). It is illegal for those electrically unqualified to work with ac voltage above 50 volts, but they may work with dc up to 120 volts as long it has next to no ac component (ripple).

As recognised in Standards, a reasonably safe voltage for working on batteries is 50 volts dc. Except in situations such as outlined above you may be marginally aware of 12 volts and get a slight tingle from 24 volts. You may feel a strong tingle from 48 volts, and quite a jolt from 60 volts dc. At that voltage and above there is some risk of harm, including being thrown off balance from a height.

The maximum you may legally work with (120 volts ripple-free dc) packs a wallop and in some circumstances could kill you. This voltage is often attained by a 72 volt dc assembly of solar modules when not connected to the solar regulator and batteries. When working on a solar array, first cover the modules with tied-on blankets.

## Batteries

A further risk is of severe burning and/or battery explosion, particularly when fitting interconnecting cables, or tightening terminals on large battery banks.



*One would not have wished to be near this when it exploded! Pic: Vinland.com*

A 1000 Ah battery bank produces short-term tens of thousands of amps. The released energy may exceed a million watts - instantly vapourising (not just melting) a spanner dropped across the main battery terminals. It is worth insulating the handles of such spanners to ensure this cannot happen.

Never wear a metal ring whilst working on 12 volts - particularly around batteries: it is only too easy for one side to contact a live cable whilst the other side is touching earth.

Always wear overalls and goggles when working on batteries, sealed or otherwise, as there is also a risk of explosion if you create a spark near batteries whilst they are gassing, or accidentally short them out. Smoking near them is lunacy. If you accidentally get electrolyte in your eyes immediately bathe them liberally in clean water and seek medical help.

## Inverter safety

The output from an inverter is just as lethal as from the 230 volt grid supply. When checked by a multimeter small inverters that revert to sleep mode when off-load appear to be electrically dead because that meter does not draw enough current to automatically bring the inverter back to life. Your fingers will.

When working on any inverter-driven system of any size, disconnect the battery positive *and* negative terminals and/or open the main switch. If anyone else is around, tape up that main switch in the off position. Many systems have fusible links that can be removed and kept in your pocket until work is completed.

# Meters & Measurement

For solar work, most measurements will be of dc voltage. A multimeter is essential. One with an audible continuity check, plus an ohms range, is very useful. You can lengthen test probe leads by several metres for voltage measurements without affecting accuracy enough to matter, but not for current measurements.

*The Fluke multimeter - not cheap but ultra rugged and reliable. Pic: Fluke.*

A range of 0 to 10 amps is adequate for single module checks, etc. but, with most such meters, measuring current involves moving the positive probe to a 'current' socket on the meter. When, as one invariably does, you forget to move it back again, next time you make a highish voltage measurement you are likely to either wreck the meter, or with most good ones, blow a protective internal fuse.

Few chainstore multimeters are suitable or reliable enough for long-term use. Most electricians use those made by Fluke.

Measuring heavier currents requires a clamp-on ammeter. For current measurements above an amp or two, there's a good case for using one anyway to avoid the otherwise almost inevitable fuse blowing if using a multimeter.

Many solar arrays have output currents of 50 amps upward, and battery discharge currents may exceed 200 amps when a heavy load is applied to a big inverter. Here, clamp ammeters are the only realistic way to obtain spot measurements. It can be done more accurately via a current shunt, etc. (page 76) but that is only convenient in permanent installations.

Clamp meters sense the strength of the magnetic field around a current carrying cable. They are typically accurate to plus/minus 3% or so. This is less than desirable but it's about the best one can do without spending serious money. To use, insert only a single conductor between the jaws, as twin conductors cancel out the magnetic signal.

## Measuring solar current output

It is normally not a good idea to short circuit a power supply. Doing so blows fuses, burns up cables, and causes general mayhem. Solar modules are an exception. They are a semi constant-current source and their current output is actually measured by short circuiting their output. This can be done either via the multimeter's 'amp' range (usually limited to 10 amps), or by short circuiting the output from the module via a short heavy cable and using a clamp ammeter to measure current flow in that cable.

Doing the above requires care because making or breaking even a 12 volt high current dc circuit causes serious arcing, enough for example to burn the end off a screwdriver or weld a meter probe to a cable. Even with a single solar module, cover it to preclude output, arrange the short circuit, and uncover it only whilst you take the measurement. Then cover it again, or wait until near dusk to reconnect.

*Clamp ammeter measures current by having one (never both) of the conductors within its jaws. Simple and effective. Pic: Digitech.*

## Measuring battery voltage

Measurement of deep cycle battery voltage is meaningless unless the battery has rested totally off-load for at least 12 hours, ideally 24 hours, or all you will measure is the charge immediately around the plates. Because of this a still close to flat deep cycle battery can present as charged after an hour or so at heavy charge. Conversely, a close to fully charged battery may present as close to flat immediately after removing a heavy load. Not realising this results in many a sound battery being discarded - and ones that are almost useless being retained - whilst the owner looks for probably non-existent suspected charging system faults.

As with water through pipes, electric current dislikes being pushed through cables. The copper conductor's resistance causes some current flowing through it to be lost as heat. As a result, the voltage at the load end will always be lower than at the source. This loss is called 'voltage drop'.

The amount of voltage drop depends on the conductor's size and length, and the amount of current flowing through it. The smaller the conductor (the copper part that carries the current), the longer the distance and/or the higher the current, the greater the voltage drop.

When calculating cable size, take into account the *total* conductor length, i.e. there and back. Ten metres between power source and appliance necessitates 20 metres of conductor. This can be as two separate conductors, or twin conductors within one sheath.

## Reducing voltage drop

The effect of voltage drop is an overall loss of power (in the form of heat). Voltage drop is minimised by reducing cable length, using bigger cable (or both). Halving cable length halves its resistance, thus halving its voltage drop. Doubling the cable size does likewise.

Another way of reducing voltage drop is to use a higher voltage. Here, the savings are two-fold. The power required to perform a certain amount of work (watts) is a product of current and voltage. A 12 volt electric jug, for example, is rated (say) as 300 watts. As volts x amps equals watts, that jug thus draws 300 watts divided by 12 volts – i.e. 25 amps. If designed to run at 24 volts it is 12.5 amps. If designed to run at 230 volts it is about 1.3 amps. The three variants heat the same amount of water in the same time. All draw the *same* amount of energy and do the *same* amount of work. Each, however, draws a different amount of current.

For appliance wiring, a realistic voltage drop is about 2%. For a 12 volt jug that is 0.24 volt, but for a 24 volt jug it is 0.48 volt. The acceptable voltage drop as a *percentage* remains the same, but in volts it is *doubled.* Meanwhile, the current is halved: the acceptable cable size thus becomes a quarter, not half, of that previously. Were there such a thing as a 48 volt (300 watt) jug, the cable could be sixteen times smaller than at 12 volts!

The above tends initially to confuse almost everyone, but think about it for a bit and it becomes clearer.

Using higher voltage (where feasible) enables the use of smaller cable: it is why long distance power lines run at hundreds of thousands of volts and some at over a million volts. Copper is expensive, and is becoming more so all the time. The cost saving on a long high-power run is enormous.

As the following page explains, it is common to use highish voltages between large property solar arrays and the rest of the system, particularly if they are a fair way apart.

## All 12/24 volts

It is *feasible* to have a basic system where everything runs at 12 volts. It is cheap, simple and reliable. Installation is easy, but heavy cabling is needed to overcome voltage drop over distance of more than a few metres.

*Relatively small cables such as this may run at 500,000 volts. Pic: Global Power Line Academy, USA).*

Using 24 volts eases cabling but, apart from fridges and water pumps, associated 24 volt products are rare. Such voltages are worth considering, but using an inverter to obtain 230 volts ac allows the use of more readily available and cheaper lighting and appliances.

## The inverter decides

In any home or property system involving an inverter (which is virtually all of them except truly basic cabins) the voltage and size of the battery bank and inverter is determined by the amount of 230 volt power you need. At 12 volts, 1500 watts is about the limit, at 24 volts it is a typical 3000 watts and at 48 volts it is typically 6000 watts. In each case the current draw is 125 amps.

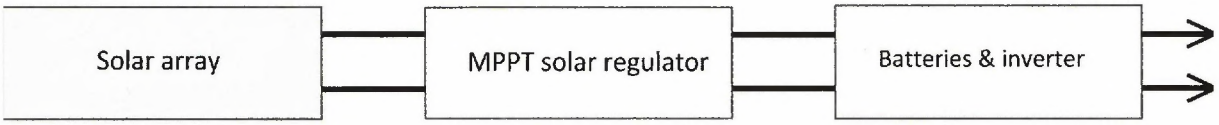
## Solar array voltage

As previously noted, voltage drop is an issue where the solar array has to be at some distance from the batteries, etc. As most of the now increasingly used MPPT solar regulators will accept any voltage from 12 to 78 volts, and some to hundreds of volts, home and property systems tend to have the solar modules interconnected to provide whatever combinations of amps and volts are electrically and legally feasible.

For example: eight 12 volt modules - each of 10 amps - may be connected to provide 12 volts at 80 amps, 24 volts at 40 amps, or 48 volts at 20 amps (pages 37-38 show how). In each case the wattage (power output) remains exactly the same: at 960 watts.

Most stand-alone system MPPT solar regulators will thus accept any such voltage - but will still charge 12, 24, or 48 volt batteries. (Grid-connect inverters output voltage is typically at a fixed 252 volts.)

Where the solar array is within a few metres of the solar regulator and batteries, it makes sense to connect the solar modules to run at the same nominal voltage as the batteries (usually 24 or 48 volts in all but the smaller cabin systems) using the size cable specified below.




*Different parts of the system can be set up to run at their optimum voltage, for example the solar array may be run from 12 volts to 120 volts or more depending on its size and distance from the rest of the system.*

If the battery bank is at a distance, and/or the array is very large, it makes sense to connect the solar modules such that they run at higher voltage. If the solar regulator allows, and many do, it is feasible to use voltages that best suit their respective parts of the system, and to specify the various cabling accordingly.

## Establishing cable size

Requirements for 230 volt cabling are specified in many national standards, and that cable's selection will be decided by the electrician doing the work.

For non-230 volts cabling, keep voltage drop to no more than 2% of the voltage concerned from beginning to end of any circuit. Some professional installers cut costs and opt for as high as 5%, resulting in energy being lost (as heat) for the life of the system and appliances not working as well as they could.

If you wish a professional to install heavier cable it is essential to instruct accordingly and be prepared to pay more for that cable, or the minimum possible size will invariably be used. Apart from limitations such as a conductor being too big to fit into a terminal, you cannot overdo cable size.

For Extra-low voltage dc circuits, establishing conductor sizes traditionally involved following wire table recommendations. These tables list various cable lengths and current flows but typically for 5% voltage drop. This is too high for solar installations. Wire tables are not suitable for work such as this, not least as they introduce gross errors.

The method shown on page 67 is adapted from the International Standard ISO 10133, Annexe A.2. It shows the cross-sectional area cable required for any combination of length, voltage and current that results in a voltage drop of 2%. From that you choose the closest *larger* size that is commercially available.

By adjusting the (here) 0.82 constant it can be readily adapted for other voltage drops, e.g. use 0.6.15 for 3% drop, and 0.41 for (a non-recommended) 4%.

Where:

S = conductor size required (in $mm^2$)

L = total conductor length (in metres)

I = maximum current (in amps)

Vo = operating voltage

S = (L x I x 0.82) divided by Vo.

For example: solar modules 10 metres from the battery bank producing 50 amps at (say) 48 volts.

L = 20, I = 50, Vo = 48. Thus (20 x 50 x 0.82) divided by 48 = 17 $mm^2$. Here 16 $mm^2$ is close enough, but AWG 4 is better (if available).

For 3% drop (20 x 50 x 0.615) divided by 48 = 12.8 $mm^2$, so 13 $mm^2$ is perfect.

As the current a cable can carry relates directly to the cross-sectional area of its conductor, electrical industries specify cable by its cross-sectional area in $mm^2$.

This is simple, obvious and practical and eminently logical. Australia, New Zealand, the European Union, and many other parts of the world, use the International Standards Organisation (ISO) sized cable for Low voltage (e.g. 230 volt) wiring. If you buy 230 volt cable from electrical wholesalers, that is what you are sold. So-called 230 volt ISO cable is rated for at least 600 volts.

The USA and Canada use the American Wire Gauge (AWG) and the virtually identical Brown & Sharpe (B&S) ratings. Both may also be quoted (and obtainable) in many other countries. The table below shows how they relate to ISO cable.

Be wary of all voltage drop tables, they are only approximate, and most assume 5% voltage drop. Use only the method shown above.

## Auto cable

Auto cable is what you are invariably sold in a hardware store if you ask for 12/24 volt cable. It is fine as a product but defies sanity by using seemingly ISO-size numbering for cabling that, in the smaller gauges, is not only a fraction of ISO cable sizes, but tells nothing at all about the product's current carrying ability.

ISO cable is rated by the conductor's cross sectional area (the bit that carries the current), and AWG/B&S of any given size has a known conductor area. Auto cable rating, however, takes no account of conductor size: the product is rated by its overall diameter *including its insulation*. That insulation thickness varies from maker to maker and even type to type from the same maker. In effect auto cable is rated by the size hole you can just push it through.

Compounding this seeming idiocy, some auto cable sizes are rated using the same *numbering* as ISO sizes (e.g. 2.5 mm, 4 mm, 6 mm) but have conductors of less than half the ISO size. Some are even smaller.

Ask for 4 $mm^2$ cable in an auto parts or hardware store and it's almost certain that what you will be sold will be 4 mm diameter (1.82 $mm^2$, or possibly 2.0 $mm^2$). The 2 mm rated auto cable is typically a mere 0.5 $mm^2$.

The table (below) includes includes four auto cable sizes, but (except for 6 mm) the comparison with ISO and AWG/B&S is only approximate. Six mm auto cable (typically 4.59 $mm^2$) is usually a good substitute for 4.0 $mm^2$ ISO. Some eight mm auto cable is likely to be about 8 $mm^2$, but that cannot be relied upon.

When selecting cable size it is best to use the formula shown. A few appliance manufacturers quote a recommended size as well as the *minimum* feasible, but commercial installers almost always use that minimum.

| **ISO** | **0.75** | **1.0** | | **1.5** | | **2.5** | | **4.0** | | **6.0** | | **10** | | **16** | | **25** | **35** | | **50** | **70** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AWG** | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 2/0 |
| **Auto** | | 3 | | | 4 | | 5 | | 6 | | 8 | | | | | | | | | |

*This table shows the closest rounded up relationships between ISO (i.e. $mm^2$), and AWG and B&S cable sizes. (B&S is virtually identical to AWG). The relationship between auto cable and other cable sizes can only be an approximation as the former may vary in their conductor/overall diameter. The exact ($mm^2$) size of auto cable is, however, usually shown in the small print on the drum.*

## Current ratings

A yet further cause of cable confusion is the wide-spread practice of marketing such cable in amp ratings, e.g. '25, 35, or 50 amp'. This 'current rating' is only an indication of the maximum current the cable can carry before its insulation melts. It tells you nothing about voltage drop - that is directly related to cable length.

*This insulation has partially melted as a result of excess current for its size. Pic: source unknown.*

A so-called '25 amp cable' may thus be perfectly fine over a metre or two, but would have a horrendous voltage drop if carrying that current over 20 metres.

Yet go into any auto parts store and you will hear buyer after buyer asking for (say) 25 amp cable - yet never asked by the vendor - 'for what purpose or length?'.

There is nothing wrong with the higher quality auto cable as such. Its $mm^2$ size is often shown in tiny print on the label, or side of the drum, and usually in the store's technical data books.

You need to be persistent when enquiring as salespeople in such stores rarely know there even *is* a rating difference - let alone of its vital importance.

Major misunderstanding relating to cable sizes is rife in much 'Do It Yourself' working. It is a known cause of innumerable 12/24 volt dc fridge and other problems and is a major cause of problems with caravan and motor home wiring.

It may introduce a life-long energy loss in solar electrical systems.

# Installing Cable

Legally, cables carrying Low voltage (e.g. 230 volts), and those carrying Extra-low voltage (e.g. 12 volts), must be physically separated unless the latter also uses Low voltage cabling. It is good practice to keep them separated. Low voltage cables must, in many circumstances, also be protected by conduit.

Specific rules govern the burying of such conduit. This is licensed electricians' territory but you can save money by digging the conduit trenches yourself. An electrician will advise the requirements relating to depth. Orange conduit is used for buried cable, grey (or orange) for non-buried cable.

Grey conduit can be used for Extra-low voltage cabling. It is available from 16 mm in diameter. Use an ample size: 20 mm and 25 mm meet most needs, but 32 mm or larger may be required for battery cables.

To pull cables through installed conduit, tie a small rag or a tissue to the end of a light, strong line - make sure its far end is tightly secured and pull that line through the conduit by using suction from a vacuum cleaner. This works surprisingly well and virtually instantly. Then attach the cable to the far end of that line, using insulation tape stretched tight along about a 100 mm length, and pull the cable through manually, ideally with another person easing it in at the far end. Sticking cable can be made less so with soapy water or WD-40.

*Typical connector. Pic: successfulsolarbooks.com*

## Terminating cables

Cable terminations usually depend on whatever is being connected: solar modules for example usually allow only for the conductors to be located under specially shaped washers, and secured by set screws.

Connector boxes have one or more holes in which the conductors are clamped under pressure by set screw/s. These boxes are handy for joining multiple cables.

The mains voltage versions are readily available from electrical wholesalers and do the job perfectly. There is a wide range of these connectors. Some accept cables up to 150 sq mm.

*Crimp lugs are colour coded for conductor size. Use only top quality products. Pic: successfulsolarbooks.com*

## Crimping tool & lugs

Some devices require crimp lugs that are used also in motor vehicles. If crimped correctly, the lug and cable form a cold weld. If not done correctly, the connection may work well enough for a year or two, but eventually fails.

Crimp lugs are made in a range of quality, from useless to excellent. The better ones are sold by electrical wholesalers. Use only those.

| Cable size (sq mm) | Lug colour |
|---|---|
| 0.5-1.5 | Blue |
| 1.5-2.5 | Red |
| 2.5-6 | Yellow |

*Using the correct size lug is vital.*

It is also essential to use the correct size lug. If too large, the conductor becomes trapped at one side rather than being mechanically crimped. Also essential is a specialised high quality crimping tool. You *cannot* do this job successfully without one.

The better ones have an adjustable preset ratchet mechanism that ensures correct crimping pressure.

Larger crimp lugs can only be successfully crimped by a hydraulic tool. Most auto electricians will do it at nominal cost.

*Ratchet crimping tool exerts enough pressure to form a cold weld. Pic: successfulsolarbooks.com*

# Protecting the Cabling

With Extra-low voltage circuits the main risk is that of fire caused by excess current heating up cabling until its insulation melts. If exposed conductors then touch, full battery current may flow, heating the conductors until they too melt. The risk of this igniting flammable material is high. To protect against such excess current flow, a circuit breaker, fusible link or a fuse is inserted into the cable close to the source of power, and rated such that it cuts current flow before the cable heats to a dangerous level.

Many, including installers, regard fuses and circuit breakers as interchangeable. In practice, circuit breakers inserted close to the power source are best used to protect cables. Fuses (inserted close to an appliance) are best used to protect that appliance against further damage in the event of failure or overload. Fuses are sometimes built into appliances or, as with Engel fridges, built into the appliance end of the power lead plug.

Over 100 years of US insurance records show fewer electrically-caused fires where circuit breakers protected the cabling. Just why is not fully understood, but there is a statistically significant difference.

## DC circuit breakers

It is good practice to include main dc circuit breakers as close to the battery bank as feasible. Each should be rated at about 150% of the maximum current likely to be drawn.

*CNC's dc circuit breakers are available for currents from 6-63 amps. Pic: CNC.*

When a dc circuit is broken, an ultra-hot arc forms between the opening contacts and is only extinguished when the gap increases considerably. This arcing generates a lot of heat. Dc circuit breakers' contacts are designed to cope with this. Some have a spring mechanism that causes them to operate very quickly. Several vendors of *ac* circuit breakers claim their products can be used to protect dc circuits (at up to 48 volts) but it is essential to obtain their advice regarding this - as the units trip in a different manner than with dc.

Following the (Australian) roof insulation saga in early 2010, that resulted in five installers' accidental electrocution and many fires, there is anecdotal evidence that, to save money, some solar installers had been using ac circuit breakers in high current dc solar feeds exceeding 110 volts. This is, to put it mildly, not good practice. The arc formed when one trips is as likely to cause a fire as safeguard against one. As dc circuit breakers can be obtained for not that much greater cost, it seems pointless to use ac units in dc circuits.

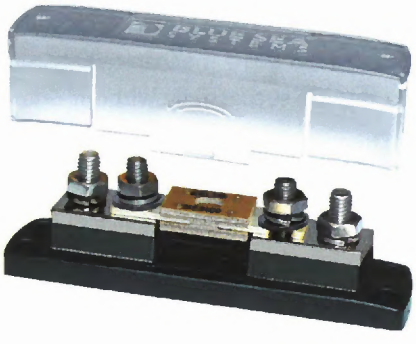
## AC circuit protection

With the mains voltage side of 230 volt systems, circuit breakers are mandatory to cut off excess current flow. As alternating voltage and current passes through zero voltage and zero current twice on each complete cycle, arcing is not sustained for longer than 100th of a second. Ac contact breakers do not, therefore, encounter the heavy arcing encountered by their dc counterparts.

The minimum time for the circuit to be broken following a fault condition is specified, and electricity authorities and regulators increasingly insist that suitably rated circuit breakers be used.

## Fuses

Never use tubular glass fuses, nor fuse holders that need fuse wire. For Extra-low voltage up to 15 amps, use vehicle blade holders and fuses. Twenty and 30 amp blade fuses are made, but there are increasing reports of fuse holder failures. Mega versions of blade fuses are available and recommended for use from 20 amps upwards. For higher currents use only the bolted-in fusible links.



*This Blue Seas fusible link is available from 35-750 amps. Pic: Blue Seas.*

# Installing (general)

Solar modules need unobstructed sun. They may be located on a roof or at ground level. Given the space there is a marginal preference for the latter, as ease of access for occasional cleaning is simpler and safer.

To minimise voltage drop the battery enclosure should be as close as feasible to the solar array. Alternatively, run the solar array at a higher voltage, or use heavier cable - or both.

The battery enclosure should be reserved for batteries only. The circuit breakers, main switch, battery charger, solar regulator and inverter need to be within a few metres of the batteries but not in the same enclosure.

Solar regulators with inbuilt metering need the read-out where it can easily be seen.

Inverter cooling fans can be noisy. Check this before finalising location.

## Solar mountings

Major savings can be made by building your own module racks but if eligible for a rebate you must first discuss and agree this with your supplier. Far from all will agree – and all have the last say.

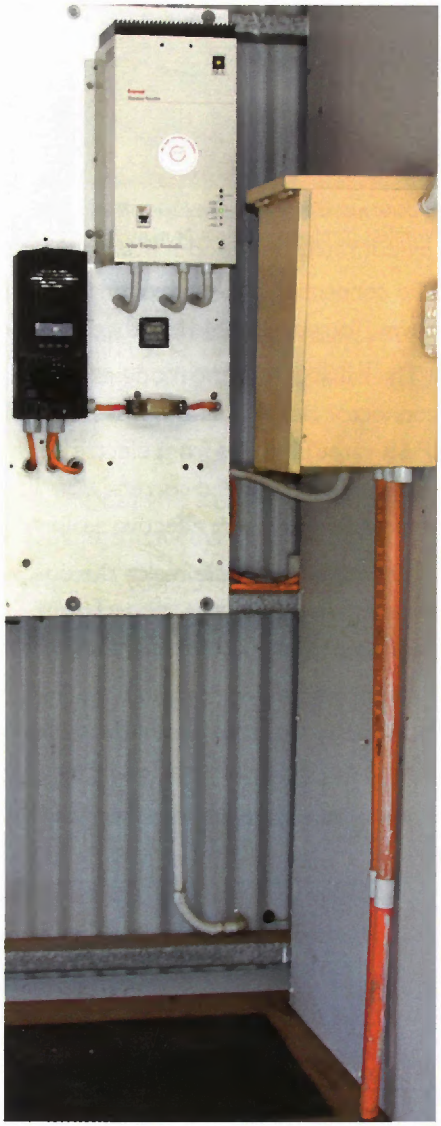
Solar module mountings must withstand prevailing winds, especially in cyclone areas. All except amorphous modules need a 50 mm air space beneath them.

The number of modules must be compatible with the array voltage: a 48 volt system will thus have four, eight, twelve or sixteen 12 volt modules, connected in series for four modules or series-parallel for those of eight to 16 (pages 37-38).

As a generalisation, install modules facing true north and at the tilt angle shown. Do not be concerned about exactness - errors of 5° make only a per cent or two difference.

If desired, you can optimise input for summer (at the expense of input in winter) or optimise input for winter (at the expense of input in summer) by tilting the modules as shown below. Or you can build an adjustable rack to enable the angle to be changed.

At latitudes numerically lower than 25° (i.e. closer to the equator) there is surprisingly little loss if the modules are horizontal. (In practice a slight tilt is advisable to enable rain to more effectively wash the modules).



*Outback Power solar regulator, 3.4 kW SEA inverter and Xantrex monitor. A 48 volt 945 Ah battery bank is behind the wall (right). Pic: successfulsolarbooks.com*

## Automatic tracking

Mechanisms that tracked the sun were common when solar modules cost far more than they do now. Module prices, however, have since fallen to $1-$2 per watt so it is now far cheaper in most locations to accept some loss and to add solar capacity to compensate. This is less true for numerically higher latitudes, but even there the trend is toward larger fixed arrays.

| Usage | Latitudes < 25° | Latitudes > 25° |
|---|---|---|
| Year round | Equals your latitude | Your latitude plus 5° |
| Mainly summer | Your latitude minus 10°-15° | Your latitude minus 5°-15° |
| Mainly winter | Your latitude plus 5°-15° | Your latitude plus 5°-15°- |

*Approximate solar module tilt angle.*

The module rack shown below was designed to withstand cyclonic wind gusts exceeding 200 km/h. It was fabricated from galvanised 'C' channels made for roof purlins. Lighter sections can be used where extreme wind strength is not an issue. X-section cross bracing is always needed. Concrete footings need to be 600 mm by 600 mm in cyclonic areas, but 400 mm by 400 mm or so otherwise.

*Cyclonic mounting for four by 120 watt solar modules that drove the swimming pool's 48 volt dc brushless pump motor at our previous home outside Broome (WA). Pic: successfulsolarbooks.com*

## Connecting modules

Most solar modules have a standard-sized connection box on the underside. The boxes have knock-out plastic circles that, when removed, accept a 20 mm diameter cable conduit connector.

Readily available 20 mm flexible conduit pushes into these connectors (do not use conduit glue as it permanently softens the flex). The connection boxes are often inaccessible once the modules are in place, so finish wiring before bolting them down. To reduce cable length, orient individual modules so that the boxes are close together.

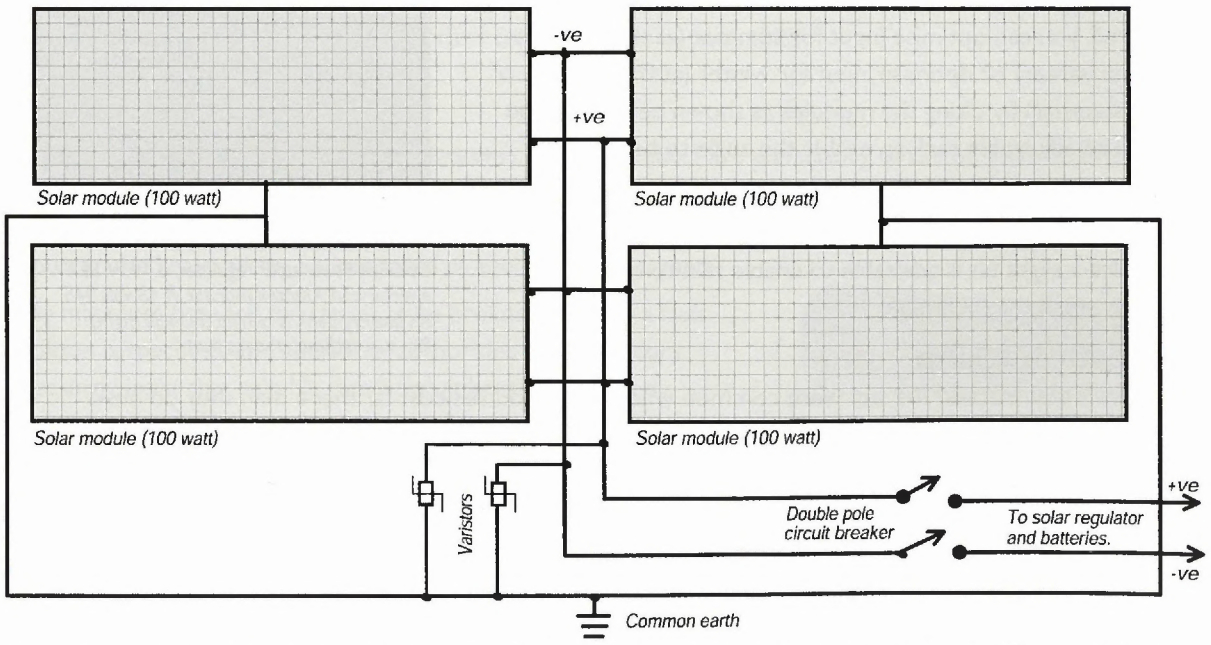
The cabling from the modules in each solar panel (assembly of modules) can be terminated in a waterproof connector box that also houses the contact breakers, varistors and common earthing strip. The (IP 65 and IP 68-rated) J-boxes from electrical wholesalers are perfect for this. They are fully waterproof if installed correctly. Similar looking but non-rated boxes from electrical chainstores may lack effective sealing.

*Flexible conduit is used to carry the solar feeds. Pic: successfulsolarbooks.com*

If there are multiple racks, the output from each should be co-joined at the point closest to the batteries, or each rack's cable pair can be run to the battery shed and paralleled there. These main array cables may carry substantial current.

As shown below, dc circuit breakers or double pole switches can usefully be included at the array end of the cable/s to enable you to isolate the solar array's input from the supply cable/s if required.

Some solar modules have blocking diodes within the connection boxes.




*Typical solar array has two pairs of 100 watt modules (each series connected) with the pairs then paralleled to provide 200 watts at 24 volts (480 watts). Note how the protecting varistors (see next page) are connected. Pic: copyright successfulsolarbooks.com*

These diodes prevent the battery discharging through the modules at night but, as that blocking function is built into solar regulators, they are only needed if (inadvisably) no regulator is used. These diodes introduce a voltage drop of up to 0.6 volt each. Most installers recommend they not be used unless deemed essential.

Do not confuse these diodes with bypass diodes (usually inbuilt). The latter assist during partial shading.

## Testing series connected modules

Before finalising, test each module using a multimeter switched to an appropriate voltage range. Keeping one meter lead at the starting end, measure the voltage one module at a time along the module chain (you can extend the meter leads by many metres without meaningfully affecting the result).

The voltage should progressively increase. If it does not, then you have inadvertantly crossed over positive and negative on the module you are checking (it is only too easy to do).

Except for single modules, do not attempt to check current unless you have a clamp meter. If you have such a meter, check the current with the module's positive and negative terminals strapped together by a short length of heavy wire. Doing so will not damage the modules – page 64 explains how and why.

## Testing parallel connected modules

Under a steady sun, and using a clamp meter as above, cover one module at a time and check the current input to the solar regulator. The current should drop by the same amount for each. If it does not, that module is faulty or not properly connected, or not fully covered.

If all is well, give the terminals a burst of WD-40 and screw down the connecting box lids. Electrically, you can *legally* do the above yourself (for solar arrays of a nominal voltage up to 72 volts - these will reach 110 volts or so off-load).

## Earthing

Strong dry winds can cause a high voltage static build up on solar modules. This can give a nasty jolt and also attract dry dust onto the module surfaces. To eliminate this, all such frames and conductive structural parts of solar arrays must be connected to protective copper covered earthing spikes - obtainable from electrical wholesalers. The earthing cables are secured via holes provided for this purpose in the module frame. If the individual modules are well earthed to the metal racks, the earth connection can be taken from that rack. Use at least 6 $mm^2$ cable.

## Lightning protection

Lightning protection, via earthing, is not likely to be effective in the statistically improbable event of a direct lightning strike. The more common risk is of nearby strikes inducing high voltages across the supply cables from the solar array to the rest of the system, and possibly in the solar array's wiring.

Protection can be provided by varistors. These are voltage sensitive devices that partially protect against high voltages, as for example may be induced in the solar array cabling described above. They do this by becoming conductive at voltages of about twice their nominal rating, typically in less than 20 nanoseconds (<20 billionths of a second), thus automatically earthing excess voltage.

To specify, pick a varistor with a voltage rating of about twice that of the nominal voltage of the solar array. The drawing on the previous page shows how they may be connected. In truly static-prone areas, or where lightning strikes are common, a varistor can be wired across each solar module. They are readily obtainable from solar suppliers and electrical wholesalers.

*Varistors can assist protect solar modules etc. against lightning. Pic: EPCOS.*

## Solar regulator

The solar regulator needs to be as close to the battery bank as possible but, if the monitoring read-out is part of the regulator (as with most), it is also necessary for that read-out to be easily read. The regulator runs fairly hot. Allow ample ventilation.

Most stand-alone energy monitors need to be within 10 metres of the batteries, but some can be up to 100 metres away (the installation manual will advise). They do not need ventilation. Most have back lighting.

Solar regulator wiring is straightforward yet many people get it wrong. Many up-market regulators have two sets of battery terminals - one heavy pair for charging current, and a lighter reference pair to provide the *exact* battery voltage needed to set the charge rate.

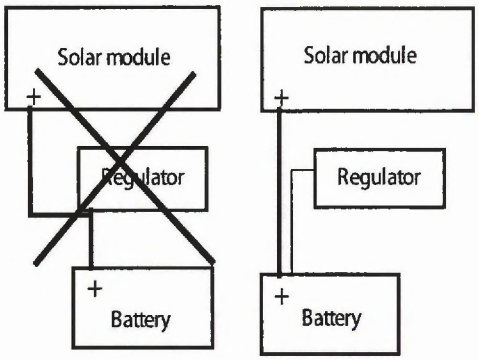
*To cut trivial cost, some installers omit the battery sensing leads, or connect them to the adjacent main battery terminals. This may preclude correct charging. Pic: Morningstar.*

Despite vendors' wiring instructions, that usually show a second pair of solar regulator to battery cables, some installers wrongly assume that by interconnecting the two sets of terminals at the regulator, they need only one cable pair to the battery bank.

That second pair (reference leads) provides the exact battery voltage. If not included, the result can be to cause the regulator to think the battery is charged other than it is. The regulator then adjusts the charge on the basis of flawed information.

## Plasmatronic PL series

A variant of this is often encountered with Plasmatronic PL regulators. Despite *totally* clear instructions, many installers omit the battery reference cable and co-join the solar module and battery cables at that reference terminal. This causes the regulator to see a voltage that is higher than that of the battery and may result in sometimes gross undercharging. One RV owner wrecked two sets of $1500 batteries through this self-inflicted mistake.




*Plasmatronic PL series (and a few other regulators) have a Bat + terminal. This must be connected only as shown on the right (see main text for why).*

Low-priced regulators may have no provision for a reference voltage. With these regulators, it is essential for the battery-to-regulator cables to have no more than 0.1 volt drop in a 12 volt system, needing the regulator to be located close to the battery.

Take the above seriously. Many solar regulators (particularly the Plasmatronic PL series) are wired incorrectly.

In some cases, the problem is simply an error, but in many cases it is done to save the trivial cost of a twin 1 mm² cable and a few minutes work. The cost to the owner, however, is a system that will never charge properly until, and if ever, it is correctly wired.

## Load terminals

Some solar regulators have a load (or similar) terminal. If you connect all loads through this terminal the regulator will show the total current being drawn. This not always feasible because that load current is usually limited by the current rating of the regulator - or even less.

A practicable alternative is to monitor load current via a current shunt and energy monitor, as shown on page 76, and to use that regulator load terminal for alternative programmable functions, such as starting and stopping generators, switching lights on and off at set times, or providing low battery voltage warnings, etc.

*PL regulator Load terminal can alternatively be used for programmable functions. Pic: author.*

## Programming regulators

Solar regulators need minor programming for time, to select nominal solar voltage, battery type and voltage, capacity, etc. and for any of the functions mentioned above - if they are needed. The solar and battery voltage may not be settable until after the battery is connected, but many regulators accept whatever voltage initially comes in to enable initial setting up.

## Energy monitors

Monitors usually need to be within 10 or so metres of the associated current shunt but some can be up to 100 metres away. For most, one pair of light signal cables and one pair of very light power cables are run from the current shunt to the energy monitor. Energy monitors usually need programming much as do solar regulators. (Connections, etc. are covered in the section on current shunts - page 76.)

## Batteries

Batteries generate oxygen and hydrogen once the charge rate exceeds 70% or so. The resultant gas ignites (fizzles) at 4% concentration, but explodes violently around 14%. This gas is routinely emitted by conventional wet cell batteries. It is normally contained within sealed batteries but all have safety vents that release gas under excess pressure. Whilst rare, this happens.

To safeguard against the above, batteries must be in a dedicated enclosure, shaded from the sun, and vented to atmosphere at top and bottom whether the batteries are sealed or not.

The following minimum enclosure vent area is suggested by the Clean Energy Council (formerly the Sustainable Energy Industry Association).

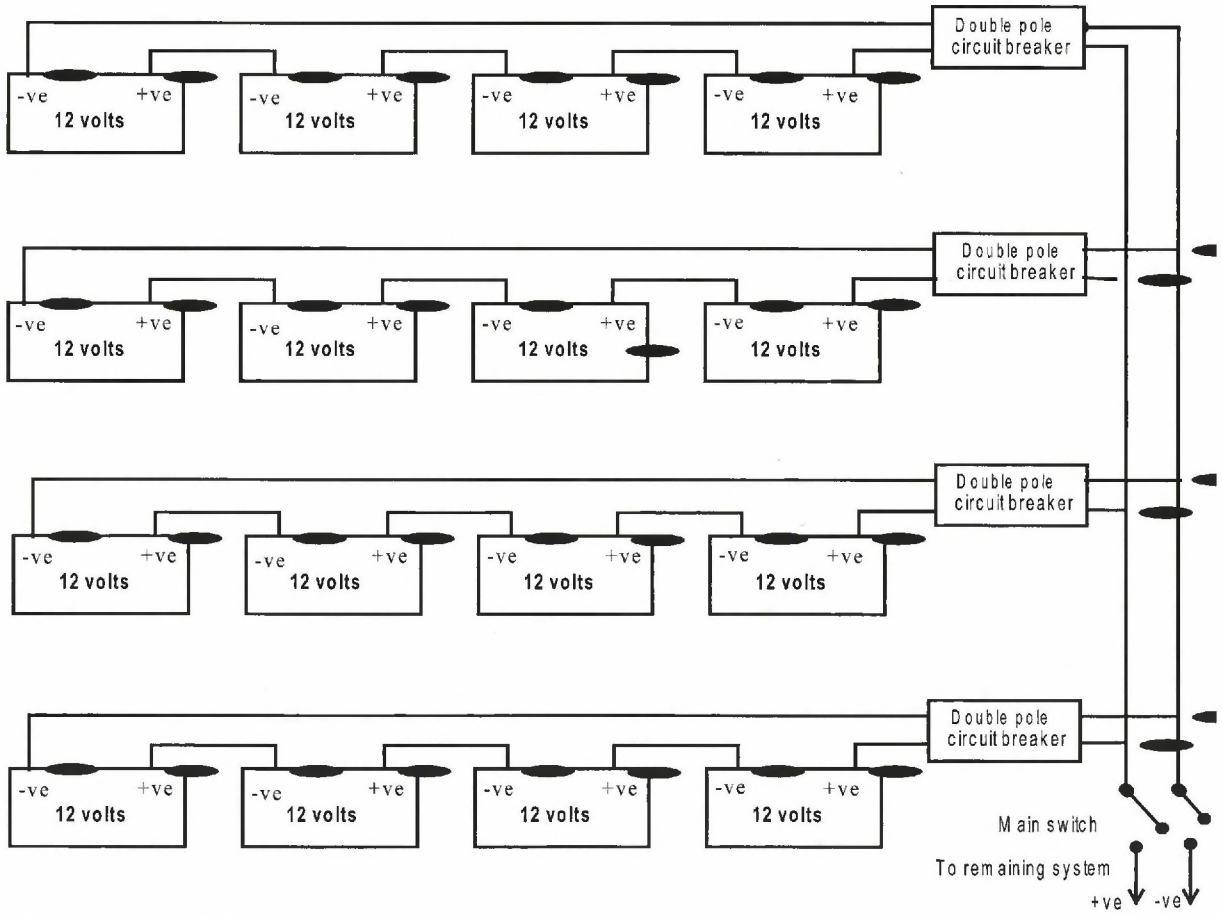
A (area) = 0.006 x C x I

Where: A = minimum area of each vent in square centimetres, C = number of cells in the battery, I = maximum charging rate in amps.

*A sign like this should be located on or close to the door to the charging area.*

A battery room containing four 12 volt batteries (48 cells) and a possible maximum charging rate of 100 amps would require not less than A = 0.006 X 48 X 100 = 28.8 sq cm for each vent.

The emitted gas is lighter than air so it rises. The upper vent thus needs locating so that gas cannot be trapped above it. The bottom vent, on the opposite side, should be as low as possible. The cable entry should be at floor level because gas seeps through the tiny gaps between individual conductors in multi-core cable.




*Typical large capacity 48 volt battery bank. Each series row has its own double pole circuit breaker. The four series rows (each 48 volts) are paralleled and then routed to a double pole mains switch. Copyright successfulsolarbooks.com*

## Large capacity banks

Large capacity battery banks are assembled from multiple smaller units. The bank, shown schematically on the previous page, is typical of many medium/large systems. Interconnecting cables are needed and each has a lug at either end. The lugs need to be crimped, never soldered. Have them made up by a solar or battery supplier (or an auto-electrician) as a hydraulic crimping tool is essential to form the necessary cold weld. These terminals should be protected by adequate insulation.

Battery racks must be ultra-strong and diagonally braced. A single 12 volt 230 amp hour battery is likely to weigh about 85 kg. Arrange ready access to battery terminals and for topping up (if relevant).

Battery terminal connectors vary in quality, from totally non-acceptable to well engineered. Avoid cheapies, they are liable to crack after a time.

## Battery chargers

Chargers big enough for home and property systems are large and bulky. Transformer versions are massively heavy. Locate the charger close to the battery bank but not in the same enclosure. A battery charger is classified legally as an 'electrical appliance'. As long as it has a supply cord long enough to reach a suitably rated 230 volt socket outlet on a generator you can simply plug it in.

Heavy cabling will be needed for the feed to the batteries. Here's an example.

Assume the charger is a 48 volt unit that charges at 70 amps. The charger is 5 metres from the battery bank so there are 10 metres of conductor. The required cable size (S) for 2% voltage drop (page 65) is:

S = (L x I x 0.82) divided by Vo (here 48 volts).

For example: solar modules 10 metres from the battery bank producing 50 amps at (say) 48 volts.

L = 10, I = 70, Vo = 48. Thus (10 x 70 x 0.82) divided by 48 = 14.5 $mm^2$. Here 16 $mm^2$ is perfect.

## Current shunts

A current shunt enables heavy load and charging currents to be displayed via an existing solar regulator display, or via a separate energy monitor. The current to be monitored flows through one or more metal strips that have a small accurately known resistance. Current passing through the shunt causes a very slight voltage across it that is directly proportional to the current flow. This obviates measuring heavy currents directly, and also the need for massive extended cabling to and from the meter. Using a shunt enables current measurement to be cheaper and more flexible.

*Typical current shunt. Pic: author.*

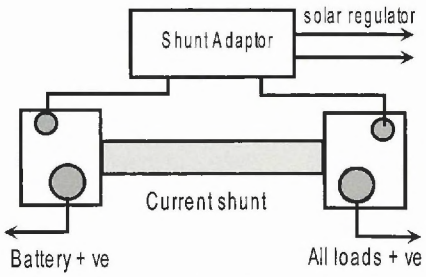
Shunts range from 50 amps maximum upwards. You need one that *comfortably* handles the maximum load or charge current and is compatible with the monitoring device. The supplier will be able to advise the size and specifications.

The shunt is usually inserted in the positive cable close to the battery master switch, but some regulators need it to be in the negative lead. A shunt adaptor may be needed. To ensure their compatibility, buy the current shunt and adaptor from the solar regulator vendor.

The current monitoring signal is taken from the shunt by a pair of light twisted leads. If the read-out is a *separate* energy monitor, the twisted pair usually connects directly from the current shunt to the energy monitor. A voltage proportioning device may be required (obtainable from the energy monitor supplier).

The maximum distance between shunt and monitor is typically 10 metres. Keep the signal cable away from other electric cables.

If using a shunt with a solar regulator that has inbuilt monitoring, the solar feed cable must go *directly* to the battery not via the shunt. If it goes through the shunt the solar input is recorded twice.

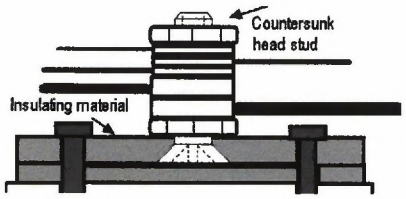



*Current shunt connects in series with a main battery cable (positive or negative).*

## Power posts

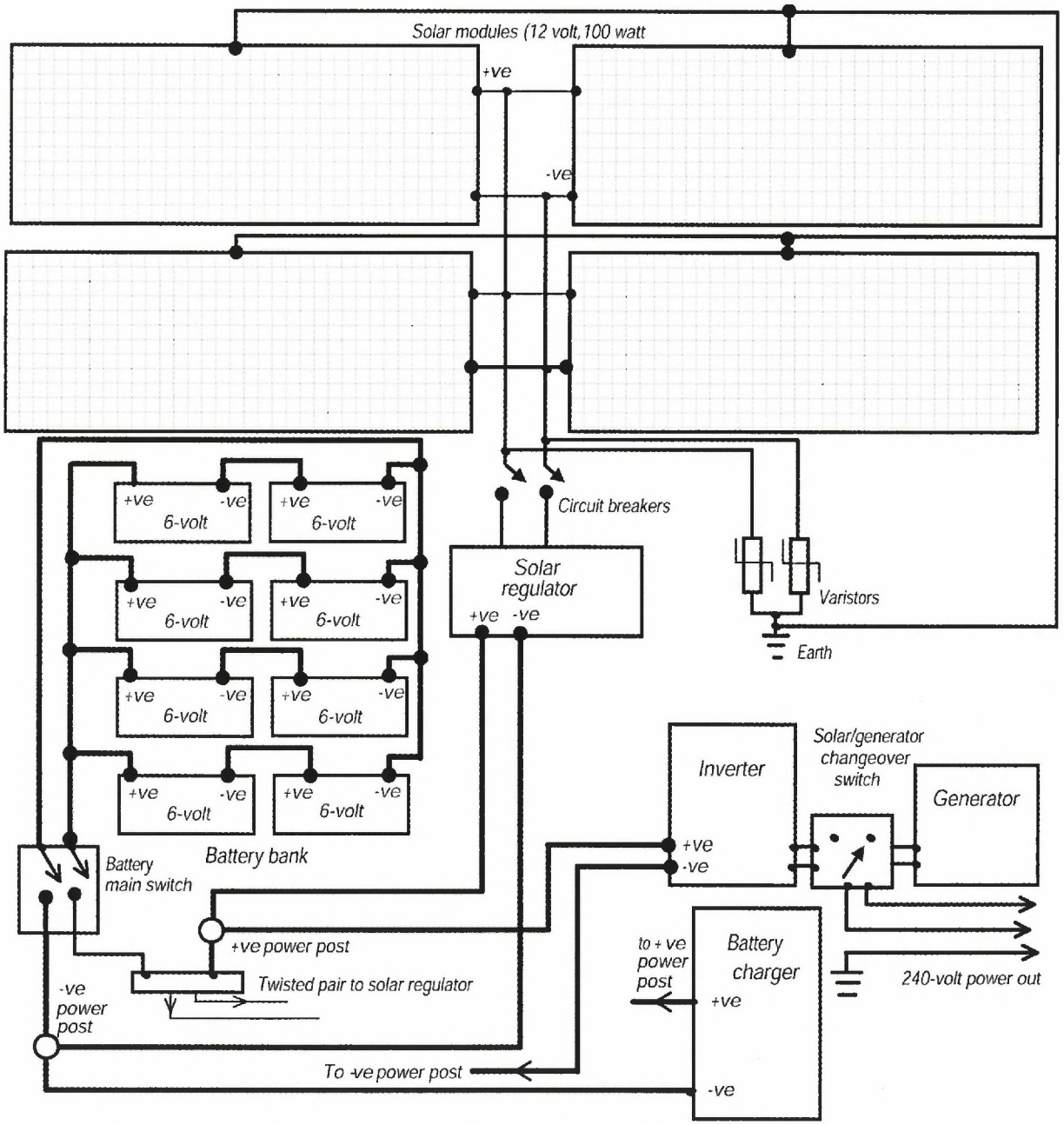
To avoid the often Xmas tree of cables connected to the battery bank, consider using intermediate power posts as shown on the right and in the drawing below. The main heavy current cables (solar regulator, inverter and battery charger) are connected to the shunt positive, and battery negative via such posts.

Power posts are stocked by marine electrical suppliers and many electrical wholesalers, but can be readily made from scrap material. Locate the heaviest current cables at the bottom of the stack and progressively upwards.




*This power post was made from workshop scrap, commercial ones are similar. Pic: author.*

The main cables from the batteries to the main switch, and those that run from that switch to the solar regulator, inverter and charger, must be rated for the maximum current flow, with no more than 2% drop from end-to-end.




*Main wiring and components of a medium-size system. Four 12 volt modules are paralleled to increase capacity. Four pairs, each of two 6 volt series connected batteries, are paralleled to provide large current capacity at 12 volts. Connections of regulator or energy monitor vary from maker to maker. A twisted pair from the current shunt may need an adaptor (not shown here) in its feed to the solar regulator. In the interests of clarity, circuit breakers in the battery circuits are not shown. Pic: copyright successfulsolarbooks.com*

## Switches for 12/24 volts dc

For 12/24 volt dc systems, some switch makers advise that their 230 volt ac switches can be used if limited to 20% of their ac rating: e.g. a 10 amp 230 volt ac switch may be used at up to 2 amps dc.

*Light switches rated for 10 amps ac are fine for 12/24 volt dc if current does not exceed 2 amps. Pic: author.*

## Power outlets for 12/24 volts

Special two-pin socket outlets are made specifically for 12/24 volt dc use. They are made by Clipsal (the catalogue numbers are 492/32 plug and 402/32 socket) and are available from some electrical wholesalers and caravan parts suppliers.

Never use three-pin sockets for this. It is hideously dangerous because the 12 /24 volt appliance lead will need a 230 volt three-pin plug. If anyone unknowingly plugs that appliance into a 230 volt socket they could be killed.

Avoid cheap cigarette lighter plugs and sockets. Most lack mechanical locking and few safely carry more than a few amps. They tend to arc internally, and become a fire hazard. (Hella, and Engel make better versions.)

*Clipsal extra-low voltage plug and socket. Pic: Clipsal.*

## Inverters

Inverters handle 150 amps or more. They need to be close to the battery bank. The transformer-based units are heavy and bulky but the more recent switch mode units are smaller and much lighter. Most are fan cooled and noisy. Their noise level should be checked before finalising location.

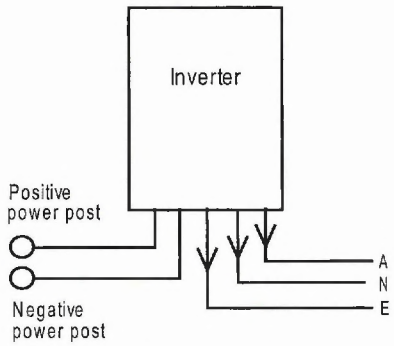
Inverter positive connects to the positive system side of the current shunt (or, if there is no shunt, the system side of the master switch positive). Inverter negative goes to battery negative.

Cable size is calculated by the usual routine. For example, assume the inverter to be an older 24 volt unit capable of a typically continuous 2400 watts with short-term surge capability of up to 3600 watts.

To cater for some surge capability, allow for 25% or so more than the continuous rating (3000 watts or 125 amps).

*This 48 volt SEA 3.8 kW (11 kW surge) inverter's surge is up to 230 amps. Pic: author.*

If that 2400 watt inverter is two metres from the battery bank, (i.e. 4 metres of conductor) this is: (4 x 125 x 0.82) divided by Vo (i.e. 24 volts) = 17 $mm^2$. Here 6 $mm^2$ is close enough.




*Inverter wiring. The cabling on the right is licensed electrician territory.*

Before switching on the power, triple check that battery positive really *is* connected to inverter positive, and battery negative to inverter negative. Triple check this: if you get this wrong you may damage or even destroy the inverter.

The 230 volts from the inverter will go to a main switch, circuit breaker/s, residual current detector/s and possibly a solar/generator change-over switch. All must be housed in an approved enclosure.

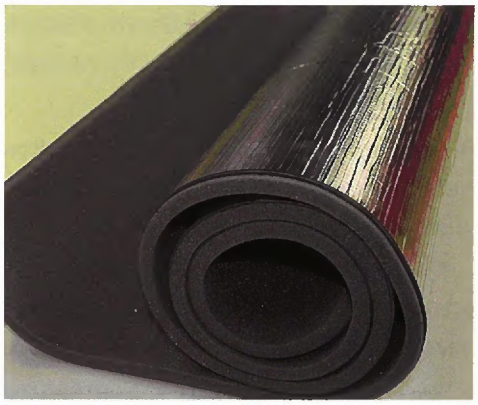
You can do the mechanical work yourself but the wiring, etc. from the inverter ac output onwards must only be done by a licensed electrician.

## Generators

Most diesel generators are noisy. Those marketed as 'silenced' are 'less noisy.' Some country people live with the racket but this can infuriate neighbours, particularly those who installed solar for its silence.

It is possible to quieten a generator but acoustic mythology is rife. The often suggested egg cartons are useless for this purpose.

Most noise from an air-cooled generator is radiated from its cylinder wall and crank case. It is impossible to quieten this directly but the sound energy can be mostly contained, and dissipated, by enclosing the generator. The enclosure can be rigid and heavy, such as concrete or limp and heavy, such as sheet lead. A good compromise is the acoustic foam/bitumen self adhesive panels made for sound insulating engine enclosures in boats. One such product is obtainable from Whitworth Marine. The catalogue number is 80204N. It is sold in sheets of 800 by 1370 mm by 25 mm and costs (2015) $85 a sheet. There are cheaper variants, but they are less effective.



*Acoustic foam. Pic: source unknown.*

Sound travels through surprisingly small openings. These can be sealed by sound insulating tape available from the same source (Whitworth catalogue number is 190202).

You will need a sound absorbing air entry and an exhaust silencer (car units work fine), plus a cooling fan.

Water-cooled generators are easier to quieten, not least because the radiator can be remotely located.

## Auto/changeover

The more sophisticated systems switch a generator on and off automatically under pre-determined conditions: e.g. 'switch generator on when battery voltage falls below 46 volts for more than five minutes, then switch back to solar when the battery voltage exceeds 54 volts for five minutes'. The ability to do this is built into up-market solar regulators and is usually accessed via the load terminal, or a terminal dedicated to that purpose. It is also built into most energy monitors.

Whilst the programming required is not that hard to do (but is often obscured by techno-babble), setting up the auto change-over switching, cabling and associated contactors can be complicated. This needs specialised knowledge: have this done by the equipment supplier, or by an electrician experienced in this area.

## Water pumps

Extra-low voltage pumps are often used in RVs and small cabins. Most are 12 volts dc and draw 4 to 7 amps whilst running and about twice that whilst starting. Their cabling should be specified for the starting current.

Most are held 'off' by the pump maintaining pressure and thus draw power continuously. Worse, if pressure drops because of a leaking or broken pipe, etc. the pressure switch will keep the pump running non-stop until the water and/or power runs out. Include an accessible switch so you can turn the pump power off when leaving the premises for any length of time.

These pumps may seize if not used regularly. If that happens they draw a lot of current and may burn out. To avoid the latter at least, include a blade fuse at the pump end of the cable.

The SHURFLO 'Revolution' has an internal bypass enabling it to run at constant pressure, with water drawn as needed: but entailing higher energy draw.

For larger systems consider the variable speed pumps described on page 32. As they draw only a third or so of the power of conventional pumps even big ones will run on single phase 230 volt ac: not only saving on running costs, but also on installation.

*SHURFLO Revolution 12/24 volt dc pumps Pic: SHURFLO.*

## Pressure accumulators

Pressure accumulators (pages 27-28) reduce short term pressure fluctuations and pump cycling. They are strong vessels of a few litres to 500 or more litres. Their upper part houses a balloon inflated to about

14 kPa (2 psi) below the cut-in pressure. This is typically 140 kPa (20 psi) in systems that have a maximum pump pressure of about 350 kPa (50 psi).

The pressure tank and switch is best teed into the water system within 10-20 metres of the pump, using the same size pipe as the main feed. The previous edition of this book suggested longer distances were acceptable, but one reader took this to extremes (1.5 km) and ran into problems.

Installing a large pressure tank reduces pump cycling from hundreds of times a day to once or twice a day. Pump and pressure switch life are extended, and power consumption slashed: in one case the pump ran for about three minutes once or twice a day, reducing energy use from 1.3 kWh/day to 0.1 kWh/day - (page 27).

## Refrigerators

The performance and energy usage of all refrigerators is closely related to where and how they are physically installed, and also how they are used. The cooling and energy draw of those running on 12/24 volts dc are also affected adversely by voltage drop.

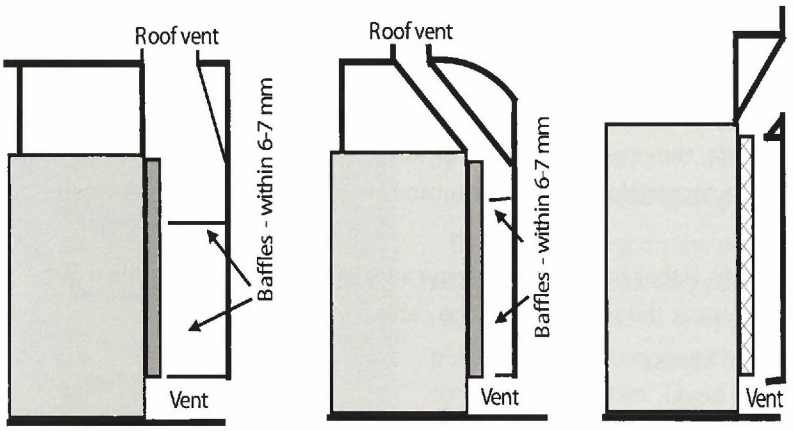
The need for appropriate installation of all fridges is gradually penetrating the industry, but it is still rare for installation to be other than 'push it into place and plug it in'. Nevertheless attending to positioning and ventilation assists cooling and reduces consumption.

The golden rule is to bear in mind how fridges work: they pump heat from where it is not wanted to where it does not matter. The drawings below show how, and how not, to do this.

Locate the fridge somewhere cool and out of direct sunlight. Heat insulate the wall behind the fridge and, if feasible, shade that wall by a fast growing bush or tree, etc.

Ventilation is essential. Some fridges have cooling fins low down at their rear: cool air must flow upward and through them. This air should enter through a screened vent, ideally from the outside, and be directed via baffles arranged such that the air is directed up and through (and *only* through) those fins. These baffles can be made of aluminium sheet, or even stiff cardboard held in place by gaffer tape or similar.

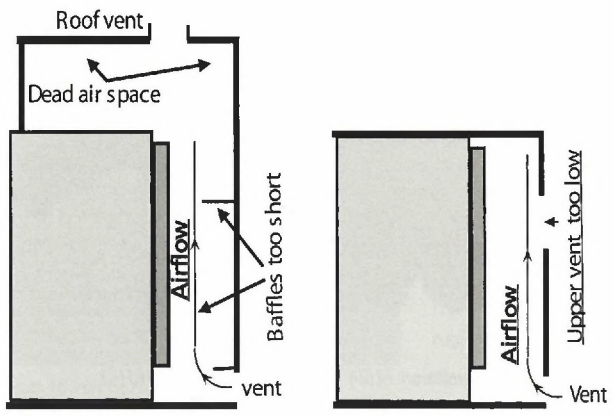
Some fridges dissipate the heat via radiation from their side and sometimes top outer skin. These too really need low level cool (side and rear) air vents. A 50 mm gap is needed around them with nothing above to trap rising air. As with all fridges, that hot rising air too should be vented to the outside.




**How to make fridges really work**
***Left:*** *baffles direct cool air over the cooling fins, and (compared with the fridge immediately below, where hot air is trapped) the rising hot air has a clear passage to outside.*

***Centre:*** *here again baffles direct cool air over the cooling fins. The rising hot air is directed by a 'chimney' to clear a curving roof line.*

***Right:*** *not ideal but where only a side wall outlet is available for the rising hot air, this will just suffice.*




**Avoid any or all of this!**
***Left:*** *baffles do not extend in far enough to be truly effective (some air will rise up clear of the fins). The dead space above the fridge is a no no. Hot air builds up and is trapped here, hindering further warm air from escaping.*

***Right:*** *this fridge has no chance of working correctly. Incoming cool air will flow up and out of the upper vent bypassing the fins. Rising hot air is trapped above the vent holding the cooling fins at an elevated temperature. Many RV fridges are fitted like this and none such work properly.*

## Fridge cable size

Older fridges run at constant compressor speed and control their set temperature by cycling on and off - typically for a few minutes each time. Their set temperature thus varies constantly by a degree or so. Many fridges still work this way, but some later units run constantly, varying their speed as required.

There is rarely a problem with 230 volt fridge wiring, but often with 12 volt fridge wiring. Fridge cooling and energy draw are adversely affected by voltage drop, and many perform badly because of this.

Assuming a 24 volt fridge drawing 5 amps, 10 metres from the battery bank, an acceptable voltage drop of 2% (0.48 for 24 volts) - and the availability of some left over 4 $mm^2$ cable where:

S = conductor size required (in $mm^2$)

L = total conductor length (in metres)

I = maximum current (in amps)

Vo = operating voltage

S = (L x I x 0.82) divided by Vo

Then, (20 x 5 x 0.82) divided by 24 = 3.42 $mm^2$ so that 4 $mm^2$ is just fine.

Never compromise on voltage drop with 12/24 volt electric fridges.

## Fusing fridges

Some 12/24 volt fridges have internal fuses. Others, such as Engel, have them within the fridge cable plug. If there is not, install a blade type fuse at the fridge-end of the cable.

## Air conditioners

Most air conditioners are installed professionally, but installers are unlikely to minimise the resultant energy draw. Whilst details are beyond the scope of the book, check ways of minimising heat transfer in and out of the cooled area, and ensure the outdoor part of a split system is protected against direct sun, and air flow over and around it is not restricted.

Air conditioners suck warm air from your room, and cycle it back in as cool air. Most have adjustable air directing fins. For cooling (as cool air falls) direct the fins toward the ceiling, this ensures more even cooling. For reverse cycle units - that can also heat - direct the fins (and thus heated air) downwards.

Some air conditioners have a 'soft start' function that reduces the extra energy usually needed. Even if your chosen unit lacks that function, transformer type inverters (but not switch mode inverters) of 3000 watts or more will have enough surge capacity to cope. If your inverter is smaller than that, check the air conditioner start-up current before buying. If it is not in the specifications, the vendor should be able to advise.
See page 50 regarding the lack of surge capacity of some switch mode inverters.

# Example 1 – small cabin

This system relates to an 80 sq m square cabin in NSW built in 2002 and progressively updated. It is close to a river that has ample water at most times and rather more than the owners had in mind at others. The cabin is used for weekends, and sometimes longer. Being on rented land, the system was not eligible for any rebate.

Water was originally hand-pumped to an elevated tank. Shower, sink and laundry were gravity fed from the elevated tank. The toilet was initially whatever needed soil enrichment. A composting unit is now installed.

Lighting originally consisted of two external 100 watt incandescents, a central 75 watt incandescent globe, and three individually switched 60 watt incandescents for reading, etc. The owners said there were usually two outside lights plus two inside lights in use for three to four hours a night.

There was good TV reception via an ancient 32 cm (14 inch) unit that drew about 100 watts. There was an even older gas fridge that was replaced by another the same size but marginally younger.

Everything electrical was run directly, inefficiently and expensively from an old and noisy petrol generator.

| Item | Watts | Hours/day | Watt hours/day |
|---|---|---|---|
| Lighting | 335 | 3.5 | 1172 |
| TV | 100 | 1.0 | 100 |
| Phone charger | 40 | 0.3 | 13 |
| Total | | | 1285 |

*Original energy draw.*

The owners later sought to run everything from solar and to install it all themselves. Their priorities were reliability, simplicity, and minimal power usage. It was suggested everything be 12 volts dc.

The existing draw (above) was high – almost entirely through using incandescent globes. The outside lighting was replaced in 2006 by a single 22 watt compact fluorescent, and the central inside light by a single 18 watt compact fluorescent (both 12 volt with inbuilt inverters). The reading lights were changed to 12 volt, 20 watt halogen. The old TV was replaced by a 32 cm (14 inch), 12 volt caravan unit.

A SHURFLO 12 volt pump was included to fill the water tank automatically when there was excess power. The previous generator-run phone charger was replaced by a 12 volt unit.

The total draw became about 215 watt hours/day (one sixth of that previously) – with pumped water now adding to creature comfort. All ran from two 100 watt solar modules.

In 2012, the compact flurorescents and the halogen reading lights were replaced by 12 volt LEDs (all of 5 watts). This reduced the lighting draw from 161 watt hours/day to about 80 watt hours/day.

Whilst two 100 watts modules are retained, the daily draw of a now 125 watt hours/day would be more than adequately supplied by only one of them, even on days of virtually zero sun. The 10 amp regulator and 100 Ah gel cell battery thus cope with total ease.

| Item | Watts drawn | Hours per day | Watt hours/day |
|---|---|---|---|
| Lighting | 20 | 3.5 | 70 |
| TV | 40 | 1 | 40 |
| Phone charger | 10 | 0.2 | 3.3 |
| Water pump | 50 | 0.2 | 10 |
| Total | | | 125 approx |

*Current (late 2014) energy draw.*

Winter irradiation is limited by shadowing but this is no problem as the cabin is not used from May through September. Minimum irradiation is otherwise about 4 PSH, rising to 6 PSH or more in summer.

## Comments

The owners followed all recommendations, buying the complete original solar system plus cable, switches and light fittings from a NSW solar supplier. They did all of the work themselves over two weekends.

The now updated result is an ultra-reliable system perfect for a casual weekend lifestyle. The solar input is more than enough (even now for the three mid-winter months when the cabin is rarely used anyway).

# Example 2 – mid-sized cabin

This example is a two bedroom cabin in Queensland with verandah sleep-outs. Built in 1980 for holiday use, by late 2008 the owners wished to use it as a more or less permanent home. The owners also have a motor home which they use for at least three months each year during the Australian winter. They also travel extensively overseas. They'd like more facilities than they have but put their limited funds into travelling, rather than their home.

The couple are unusual in that, whilst non-technical, they had a very good idea from their motor home experience of what's feasible with solar, and what's not.

The cabin originally had basic 230 volt wiring fed from a petrol driven inverter/generator. There was a small gas fridge. In 2006 a local electrician friend suggested the 12 or so lights be replaced by compact fluorescents; that they install an LCD TV no larger than 81 cm (32 inch), that gas be used for cooking, and that a 400 litre solar water heater be installed on the roof. The owners felt that, having been used to living with a 150 litre fridge in their motor home, they'd be happy with a 170 litre, 24 volt unit in the cabin. The electrician suggested the most probable energy usage would be as shown below.

The owners had not previously considered grid-connection, but as grid power was available it made sense to use it – not least because the (then) $8000 rebate would substantially pay for the small 1 kW system required.

There was also a 44 cents per kWh feed-in tariff that returned a typical $45 a month (when the cabin was not used) until 2028!

| Item | Watts drawn | Hours/day | Watt-hours/day |
|---|---|---|---|
| Compact fluorescents 18 W | 108 | 5 | 540 |
| Fridge 170 litre | | | 1000 |
| TV 81cm (32 inch) LCD | 225 | 2 | 450 |
| Washing machine | 1200 | 0.2 | 240 |
| Dishwasher (drawer type) | 1000 | 1 | 1000 |
| Kitchen appliances | 600 | 1 | 600 |
| Contingencies | 500 | 1 | 500 |
| Total | | | 4830 |

This was a generally good recommendation, but a suggested 400 litre solar water heater was overkill for two people. A 210 litre solar heater would have sufficed.

The proposed 170 litre fridge is a bit small and it seemed pointless to run an inefficient 24 volt unit via a 230/24 volt converter as grid-connect was available. An ultra-efficient, 220 litre, 230 volt unit was installed instead. The allowance for kitchen appliances is higher than needed.

With the bigger but efficient fridge, half the lights on for about five hours each day, and reduced appliance and contingency allowances, the average daily usage was 4.83 kWh/day.

The 1 kW grid-connect system installed supplies all the owners' day time needs except in mid-winter when they are rarely there anyway (and during which an average 3.5 kWh per day gets pumped back into the grid). There's a larger surplus in mid-summer. Year round this system is more grid supplier than grid user.

## A 2013 update

The system was updated in 2013. A new 220 litre fridge now uses about 300 Wh/day, an LED TV about 100 Wh/day, a washing machine about 200 Wh on its cold cycle. The lighting is mostly 5 watt LEDs. Energy usage is about 2.25 kWh/day.

| Item | Watts drawn | Hours/day | Watt-hours/day |
|---|---|---|---|
| LEDs 5 W | 30 | 5 | 150 |
| Fridge 220 litre | | | 300 |
| TV 81cm (32 inch) LED | 100 | 2 | 100 |
| Washing machine | 200 | 1 | 200 |
| Dishwasher | 700 | 1 | 700 |
| Kitchen appliances | 300 | 1 | 300 |
| Contingencies | 500 | 1 | 500 |
| Total | | | 2250 |

# Example 3 – twenty acres in WA

The property owners are semi-retirees with twin daughters – all into horses. The house is energy-efficient. Cross-ventilation negates any need for air conditioning. The (3.5kW) stand-alone solar system originally had generator assist year around. The owners wished to run mainly on solar but needed more lighting.
The original usage is shown below.

All incandescents were replaced by compact fluorescents, and by judicious use of time switches, the average time for lighting was reduced to three hours a day. The fridge was replaced by a new 507 litre fridge-freezer drawing 1600 Wh/day. The oldish computers were replaced by laptops.

Replacing the 20 mm diameter piping by 50 mm for the main 400 metre run, and adding a 500 litre pressure tank slashed pumping draw by 75%. The washing machine was replaced by a large top loader that draws only 200 watts, run once a day using cold water.

| Item | Watts drawn | Hours/day | Watt hours/day |
|---|---|---|---|
| Lighting 10 by 22 W | 220 | 4 | 880 |
| Lighting 20 by 100 W | 2000 | 4 | 8000 |
| Fridge 500 litre (old) | | | 3300 |
| TV 66 cm (26 inch) (old) | 300 | 3 | 900 |
| Washing machine | 1350 | 2 | 2700 |
| Dishwasher | 1400 | 2 | 2800 |
| Appliances, etc | 500 | 1 | 500 |
| Computers (3) – desktop | 900 | 6 | 5400 |
| Water pumping | 1750 | 2 | 3500 |
| Horse stuff | 500 | 2 | 1000 |
| Power tools, etc | 250 | 1 | 250 |
| Various | 500 | 1 | 500 |
| Total | | | 29,730 |

These under $10,000 changes enabled the *existing* solar capacity to provide self-sufficiency almost all year with occasional generator use during June/July. The late 2014 usage (about 11 kWh/day) is shown below.

By spending less than the generator cost for 18 months' fuel, energy use has been slashed by 58% – enabling a previously too small system to cope almost year round. On top of that, fuel bills were reduced by over 90%.

## A possible update

By using 5 and 8 watt LEDs and a few compact fluorescent globes the lighting draw can be cut from 2000 Wh/day plus - to about 750 Wh/day. An efficient 500 litre fridge would use about 1000 Wh/day, an even better water pump would use about 350 Wh/day and a dishwasher (still used twice a day) about 1600 Wh/day. The total that could be saved is about 3800 Wh /day - thus requiring only 7.1 kW/h day. This would enable either a smaller solar system to be used (certainly less battery capacity) or the existing one and with only very rarely needed generator usage.

| Item | Watts drawn | Hours/day | Watt hours/day |
|---|---|---|---|
| Lighting 20 by 18 W | 360 | 3 | 1080 |
| Lighting 15 by 22 W | 330 | 3 | 990 |
| Fridge 507 litre (new) | | | 1600 |
| TV 66 cm (26 inch) new LCD | 150 | 3 | 450 |
| Washing machine (cold) | 200 | 1 | 200 |
| Dishwasher | 1400 | 2 | 2800 |
| Appliances, etc | 500 | 1 | 500 |
| Computers (3) laptop | 280 | 3 | 840 |
| Water pumping | 700 | 1 | 700 |
| Horse stuff | 500 | 2 | 1000 |
| Power tools, etc | 250 | 1 | 250 |
| Various | 500 | 1 | 500 |
| Total | | | 10,910 |

This is an exceptional example that reduced usage from an original close to 30 kW/day to a now feasible just over 7 kWh/day - but shows what is possible without any really major changes.

It is a great example of this book's major thrust: to minimise what you use before you think about solar!

# Example 4 – a home (anywhere)

This is an exceptionally interesting example that has been followed over many years. Almost all of the solutions were worked out initially by a then 16-year-old student who later sent me the details for this book.

The home is a small property on a largish block in south-east Queensland and is connected to the grid. It originally had un-insulated timber walls and a marginally heat-insulated, dark corrugated iron roof. Cooking was via gas, and water heated by a couple of instantaneous electric heaters dating back to the early '50s.

The property was lit throughout each night (for perceived security reasons) by four, 100 watt incandescent globes plus three 150 watt spotlights.

Natural lighting was poor and the beige walls sucked light like a spectral vacuum cleaner, requiring indoor lights (all incandescents) to be on 16 hours a day. The living area had three by 75 watts, the kitchen had two by 100 watts. Each bedroom had a 60 watt reading light, plus a 50 watt overhead light. The windowless bathroom had a 40 watt incandescent globe – left permanently on.

There was and still is a 66 cm (26 inch) colour TV which, back then was left on all day. A VCR was also permanently on, as was a relatively modest hi-fi system that was rarely if ever used.

The ineffective fridge was over 25 years old and leaking 'cold' to the extent that it had no 'off' cycle. The energy-hungry dishwasher was run twice each day. Overhead fans in each room attempted, with little success, to cool the summer heat. Bedroom fans ran all night.

An old 200 litre chest fridge was left permanently on year round although used only to chill slabs of beer for the occasional party. There was also an electric fruit dryer that was used for days on end, but often to dry less than a kilo or two of fruit. Of the family's little money, a fair bit went to pay the huge electricity bill.

The daughter, an avid environmentalist with a scientific bent, elected to quantify the household's electricity usage as her final year school science project.

The table shown here is a summary of that data. The daughter's project noted that she was 'appalled by the energy waste'. She left school for university soon after, but not before she and a local electrician effected major savings.

| Item | Watts | Hours/day | Watt hours/day |
|---|---|---|---|
| Lighting – living area | 225 | 18 | 4050 |
| – kitchen | 200 | 18 | 3600 |
| – bathroom | 40 | 24 | 960 |
| – external | 850 | 12 | 10,200 |
| Dishwasher | 2500 | 3.5 | 8750 |
| Washing machine | 200 | 1 | 1200 |
| Fridge (425 litre) | 210 | | 5040 |
| Fridge (outside) | 150 | 24 | 3600 |
| Kitchen appliances | 500 | 1 | 500 |
| Fans (six by 75 W) | 450 | 8 (min) | 5400 |
| TV | 395 | 8 (min) | 3160 |
| Various (incl. water heating) | 3000 | 2 | 6000 |
| Total draw | | | 52,460 |

Lighting *alone* was responsible for 40% of the total (then over three times the national average). Even though the town had a close to zero crime rate, her father argued that 'we don't get break-ins with lights like this!' but agreed to cut it back to six 18 watt fluorescents.

She heat insulated the walls, had the roof painted light grey and painted the interior in less light-absorbing colours which, together with curtains open during the day, eliminated the previous need for daytime lighting. Increasing ventilation also eliminated the need to use two of the fans, and halved the usage of the remaining four. All inside globes were changed for (the equivalent light output) compact fluorescents.

The old electric water heaters were replaced by a 330 litre solar hot water heater.

Presenting her father with the knowledge that running the chest fridge all year round was costing $200 (each slab of beer costing far more to cool than to actually buy), solved that issue there and then.

The dishwasher's draw was absurd and was replaced without 'too much opposition' from dad by a larger but still old one that was used only once a day.

The worn-out fridge was replaced by a more efficient unit of similar size. Minor changes included replacing the bathroom light switch by a motion sensor, and using the washing machine on cold cycle only.

The 'leaving the TV on' culprit was her 11-year-old brother. That was fixed by interesting lateral thinking: she told her father how much it was costing in electricity and he deducted it from the boy's pocket money.

## The costs

All of the work required, excepting for the electrician changing the bathroom light switch (at a $20 'mate's rate'), and installing the solar water heater, was done by 'a not totally willing' father, and the daughter.

Here is a list of the costs incurred.

Roof: cleaning and priming, plus two coats of a light colour paint – approximately $350

Insulating bedroom walls – approximately $200

Painting inside walls in living area and kitchen – approximately $75

Twenty 18 watt compact fluorescent globes – approximately $100

Second-hand but efficient fridge – $500

New solar water heating (incl installation) – $3100

Total – approximately $4550.

## The savings

| Item | Watts | Hours/day | Watt hours/day |
|---|---|---|---|
| Lighting – living area | 54 | 5 | 270 |
| – kitchen | 54 | 3 | 270 |
| – bathroom | 18 | 1 | 18 |
| – external | 108 | 12 | 1296 |
| Dishwasher | 2000 | 1.5 | 3000 |
| Washing machine | 200 | 1 | 200 |
| Fridge (425 litre) | 150 | | 1800 |
| Kitchen appliances | 500 | 1 | 500 |
| Fans (four by 75 W) | 300 | 4 | 1200 |
| TV | 395 | 3 | 1185 |
| Various (incl. water heating) | 500 | 1 | 500 |
| Total draw | | | 10,240 |

Electricity costs for 2002 were $2680 (52.5 kWh day x 365 at 14 cents a kWh). Since the changes were made, yearly costs have (now) averaged $525. The cost of the electrical changes was fully recovered in two years.

The subsequent savings were accumulated to help pay the cost (after rebate) of a 1.5 kW grid-connect system, implemented when she finished her first degree (she subsequently completed a Master's in electrical engineering). During summer solar now provides all day-time power.

This example shows just how much energy (and money) can be saved by relatively minor changes, plus an environmentally aware teenager's realisation that power usage was *seriously* wrong.

An interesting aspect is that the then 17-year-old daughter was able to persuade her family to make the changes. I am grateful for a comment made by one of those kind enough to vet the draft copy of the first edition of this book. 'It's hard to change what you do yourself, it's even harder to change what others do'.

## A 2015 update?

First suggested in 2013 but still (2015) seemingly not negotiable, a major saving could be made by cutting back the outside all-night lighting. A compromise, however, could be to replace three 10 watt LED floodlights (about $40 each) thus saving 865 Wh/day. An efficient fridge would save another 800 Wh/day. A more efficient TV would save another 0.5 kWh/day. It is thus possible to cut usage to about 8.25 kWh/day and worthwhile as electricity costs continue to rise.

My thanks also for the daughter's assistance for once again editing these two pages.

# Example 5 – working from home

This example illustrates a still excellent use of grid-connect. The joint owners are an architect who does design work for a large building firm, working mainly from the home office. His wife, also an architect, is a spare time sculptor with an occasional need to hire and use heavy arc, MIG and TIG welders, plasma cutters, etc. Both are environmentalists and aware of what's needed for sustainable living.

The owners already had a well designed stand-alone solar system obtained as part of a debt repayment. The system was originally and subsequently self-installed and not eligible for rebate.

Unfortunately an energy audit was not obtained prior to the changes but the system at the time provided sufficient energy for some 90% of the owners' needs except when heavy metal working was involved. A small diesel generator made up the deficit. The welding and plasma cutting equipment drew high current but as it was used only for short periods it did not consume much extra power. The peak draw, however, was massively higher than the existing inverter, batteries and generator could supply. A trailer-mounted diesel generator was hired when necessary. This was inconvenient and costly, and neighbours complained of the generator's noise. An alternative solution became imperative before the neighbours sought an injunction!

Realising that the system's batteries were close to failure, a solar consultant suggested they used the still well-working modules as the basis for a grid-connect system (the grid now being only 50 metres distance) and to allow a grid-connection to handle the heavy metal working loads.

The consultant believed that eliminating the 10% to 15% battery charging/discharging losses, and gaining a further 10% via the higher efficiency of an MPPT grid-connect inverter/regulator would more than provide sufficient extra energy to make up the existing 10% deficit. It would also, he felt, achieve the owners' desire to be energy neutral.

A few sums showed that the total cost of having power laid on and the grid-connect link made was $15,500. A rebate application was accepted for the cost of the new components required for the grid-connect additions plus installation.

The consultant's assumptions including the costing proved to be spot-on. The system works perfectly and, averaged over years since, is a minor net energy exporter.

From 1 January 2010 this system *really* started paying off - on that date the NSW government began paying 60 cents per kWh for all output from such systems - including the component used by its owners. That is still current for all early such systems, but in 2012, the NSW government removed that incentive for any new systems.

Whilst not currently an issue with this system, when that huge tariff rebate ends (in this case in 2017), grid-connect continues to works well here as most of the energy usage is during the day - when there is ample solar input.

# Constructing a Stand-alone System

It is illegal for any but a licensed electrician or electrical contractor to design or install any grid-connected system. It is, however, legal to design and install stand-alone systems using voltages that do not require an electrical licence: i.e. below 120 volt dc ripple free, and 50 volts ac. In practice this limits them to a 72 volt solar array (as that will produce about 110 volts dc off-load). Many property systems run at such voltages. The most common battery banks in systems over 2.5 kW are 48 volts.

Despite it being legally feasible, this book discourages inexperienced people from attempting to design and build their own systems unless they can obtain known competent assistance throughout the project. For any system above cabin-size, consider having an independent Clean Energy Council accredited engineer (page 99) undertake (or at least check) the design before you seek quotations for equipment and installation.

Construction requires electrical and mechanical knowledge and experience, but there are many people out there (e.g. ex-telco technicians, ex-armed services electricians, electrical engineers), etc. who have the necessary knowledge and experience. Many have successfully built such systems.

Subject to possible council requirements, you can build the stand-alone system that you want, how you want and where you want. You can locate it on rented land, build it on the back of a flat bed trailer, have the modules on the roof of a coach and the batteries and inverter in underneath lockers, change anything you wish or move it all to a different site. Or even on a boat towed ashore (as with that shown below).

The requirements for connecting a 230 volt supply to or from a 'transportable structure' are different from fixed premises. The work must be done by a licensed electrician. You cannot legally do this work yourself.

You can, however, legally connect a portable inverter to a dc supply (most such inverters are 12 volt). These inverters have one or two 230 volt outlet socket/s inbuilt. Appliances may only be plugged *directly* into such inverters. They absolutely must not be connected into fixed wiring.

If you know enough to design and build a legally acceptable system, you are well able to maintain it. This can be a major long-term cost saver as faults are often trivialities such as loose battery terminals.

You forgo rebates, but in many cases you will end up in front, not least as installers may charge full retail price for everything involved.

*This solar-powered converted A-class catamaran owned by Envirotec's Dick Clarke assists to power his Belrose (Sydney) office when not out sailing! Pic: Dick Clarke, Myall Lake, NSW 2013.*

Installing these systems is labour intensive so serious savings can be made if you are able to do part or all of the work. Travelling and possibly accommodation adds a great deal more in outback and country areas.

Installers usually sub-contract the solar module racks' concrete footings, or rent a $175/hour trench digger, then have a concrete truck deliver as little as one cubic metre. Digging trenches, and mixing and pouring concrete is not for the unfit, but is not a major task otherwise. Assuming you have a generator, hire a mixer (about $50) for the day.

Even cheap ground-located commercial module solar modules racks cost $600 to $900 each (for a four or six module unit) plus installation. By way of example, the far stronger cyclone-resistant racks (page 94) were fabricated and installed in one a day for under $200 each. It would have been only $130 or so if cyclonic construction had not been essential. A quote for supplying the main array's seven racks (each of six modules) was $5500 plus another $3000 for installation. It cost less than $1500 in all.

By buying all the bits from one of the major solar equipment suppliers one can usually negotiate to obtain them at close to trade price.

The table (below) shows the likely cost of a typical 3.6 kW outback stand-alone system, excluding labour. The individual prices are those quoted by major local suppliers, but many confirmed that major discounts apply if most are bought from the same supplier.

| Components | 3.6 kW | Size | Approx cost |
|---|---|---|---|
| **Solar modules** | 16 | 175 watts | $4200 |
| **Module racks** | 4 | four modules | $2400 |
| **Concrete footings** | 4 | 400 x 400 x 2000 mm | $1500 |
| **Solar regulator** | 1 | 48 volt, 70 amp | $750 |
| **Inverter** | 1 | 3800 watts | $3800 |
| **Batteries** | 16 | 12 volts (230 Ah) | $10,000 |
| **Charger** | 1 | 48 volt, 60 amp | $700 |
| **Circuit breakers** | 6 | 100 amp dc | $600 |
| **Cable/connectors** | | | $500 |
| **Main switch** | 1 | 100 amp | $70 |
| **Total** | | | $24,520 |

*Approximate averaged prices (late 2015) prior to bulk discounts, rebates, etc.*

Solar module prices are still fluid, particularly for a bulk purchase, but the huge decrease since 2010 is not likely continue.

For the 3.6 kW system (left) self-constructing the solar module racks and concrete footings, and using ex-telecommunication company batteries, is likely to reduce the cost by $10,000.

Be wary of buying any *complete* second-hand system. The chances of finding one that is right for your needs is low. You are likely to scrap a fair part of it.

# Living With Solar

More so than with grid-connect, stand-alone solar systems makes one conscious of energy wastage even if much of the time you have ample power to spare. Lights are not left on unnecessarily, unwatched TVs are not left running with sound turned down, nor turned off only from the remote control. One buys only energy efficient electrical appliances. Dripping taps are immediately repaired, and less water is used whilst showering.

## Visitors

Then visitors arrive! Lights are left on day and night, showers are used until they run cold. The TV may be left on all day with the sound turned down, and/or computers used to play video games for hours on end, then left on all night.

This is a hard one with stand-alone systems (without using a standby generator). We *partially* solved it by furnishing a visitors' cabin some 400 metres from the main house, with its own bore-fed solar hot water system, and bore water used also for toilet flushing and laundry.

Visitors still wasted bore water but as we used less than 0.2% of our allocated yearly amount, and that unused 99.8% flowed into the ocean 300 metres away, those 15-minute showers ceased to be a problem.

A 60 litre chest type Waeco fridge set up to run from 230 volts was run from the property system, and a three-burner LP gas top provided visitors with basic cooking facilities. Lighting, however, was not an issue even if left on all day. The extra load of two 15 watt compact fluorescents was barely noticed by the main 18 kWh/day system.

Major problems may arise (with stand-alone systems) with caretakers unaccustomed to life away from the 230 volt grid. Energy usage typically escalates (and/or batteries wrecked by nightly flattening). The only solutions are to have an uneconomically oversized system or, as do many such property owners, have an automatically starting diesel generator – and to accept the resultant fuel bill. Or no caretakers.

*Pic: greenerlivingideas.com*

## Puzzling solar input

Systems with adequate solar capacity often surprise new users by there being no more daily input during days of full sun than during days of less sun. In most such cases there's absolutely nothing wrong. The solar regulator knows the battery's state of charge and when it is fully charged it cuts charging right back and into a 'floating mode'. In that mode, the charger supplies only what goes out and makes up for internal battery losses. During such times the system has the *potential* to supply more energy, but it will only do so if that energy is needed. When a heavy load is applied, the charger kicks back into full boost mode.

This is the time to do big loads of washing, or those long delayed arc welding repairs to the trailer.

## 'Leaking' batteries

This comes up now and again. People unaccustomed to solar systems often worry about more energy coming in each day than goes out. They suspect the batteries somehow 'leak'.

This phenomenon is normal. It is not that batteries leak but rather that energy cannot be turned from one form into another form with 100% efficiency. Energy is lost through inefficiencies in charging and discharging. The loss varies with battery type and capacity (less with AGM, gel cells and lithium ion), and battery age.

## Solar modules

Solar modules need *occasional* cleaning, particularly after a long dusty summer. Dry winds cause static charges that attract dust. Then, a light rain shower turns the dust into mud, but often insufficiently to flush it off.

Fix both issues by washing the modules gently with water and detergent. Then rinse with a bucket of clean water to which you add one teaspoon of detergent (it has anti-static properties). Use a squeegy to remove surface water, and then let the modules *dry naturally*, i.e. do *not* rinse further, nor wipe dry, let alone polish, as doing so generates dust-attracting static charge.

Apart from the above, solar modules need no maintenance. It is still difficult to forecast their usable life-span, but many made installed in the 1980s still work reasonably well. Total failure is very rare.

## Reliability

Solar reliability of a well designed and installed system is *way* ahead of the grid's. The output is cleaner and voltage barely wavers.

Traditional technology batteries need topping up with water every six weeks or so and it is essential this be done or they will fail long before their time.

Sealed batteries have a shorter life span than is theoretically obtainable from wet cell batteries but, as very few of the latter are sufficiently well maintained to last as long as they can and will, by and large it pays to use the sealed versions.

## Monitoring

Monitoring is essential and many new users maintain a daily log of energy in and energy out, and highest and lowest daily voltage, but later settle for checking battery percentage charge every second day or so.
The latter is all that is needed as anything that needs attention will cause significant variations.

# Our Own Systems - 1994-2015

In 1971 I founded what became the global magazine, *Electronics Today International*. Then, solar was mainly a promising and costly concept. Its practicality, for me, began in early 1994 when my wife and I fitted an 80 watt Solarex solar module, regulator and 100 Ah deep cycle battery (driving a 40 litre fridge and few lights) to our restored 1974 Kombi - that we then drove extensively across the outback.

*Our previously-owned OKA in camp near Jim Jim Falls in Kakadu National Park. Pic: author July 1997.*

In 1996 we converted our off-road OKA into a motor home. Two Solarex modules charged batteries that ran a 70 litre Autofridge, satellite phone and halogen globes. They also drove a computer, printer and a sat-phone linked fax machine.

I wrote most of my first book (in this field) in the back of it.

In 1998, returning from Darwin to Sydney, we detoured to Broome (in the far north of Western Australia) and there bought 10 acres of ocean frontage. The OKA then became home whilst we self-built our home. The OKA served also as cyclone-protection in year 2000, withstanding plus 160 km/h gusts.

*Ocean end of our previous 10 acre property at Coconut Well, Broome. In front of the house is a tidal lagoon that filled twice daily from the Indian Ocean (in the background). Batteries, etc. are in the shed close to the main 100,000 litre rainwater tank. (The colours here are not enhanced. The Kimberley coast really is this colour.) Pic: just prior to its sale in August 2010. It was a hard place to leave!*

The property had (and still has) no supplied services. With the closest grid feed $500,000 away, we first designed and built an (initially) 2 kW system that drove a 48 volt 3.8 kW SEA inverter. The modules were installed on the roof of a now derelict shed 400 metres from the house site. That system's 11 kW surge capacity enabled us to self build our 186 square metre concrete, steel and glass home using none but self-generated power.

## The house's structure

The house was originally designed by an architect who is no longer practising. The design concept was excellent but needed substantial redesigning to meet cyclone requirements. The final structure was closer to bridge or ship building than house construction. Apart from the shower and toilet it has no internal walls.

No Kimberley builder approached would touch it, so except for having contractors for the roofing and concreting, we built it ourselves with help from a local with building experience.

The 56 pages of structural drawings, and subsequent steel work were superbly provided by B & J Steel in Broome.

*Ochre tinted polished concrete floor. Pic: successfulsolarbooks.com*

The house is built on an ochre tinted, sealed and polished 200 mm concrete floor. Forty 100 mm by 100 mm (4 mm thick) RHS steel columns at 1.8 metre centres tieing down the 4.3 metre double curvature roof.

External walls are mostly cyclone-proof toughened glass and stainless security mesh sliding screens. There are 15 'front doors.' That used depended on whichever was climatically suitable at the time. There was no need, nor provision, for air conditioning.

The virtually bolt together design and construction allowed us to move in within five months.

## Extending the solar

The original 630 Ah (48 volt) battery bank was badly damaged by chronic overloading whilst we were away from the property.

It might have lasted longer but was replaced in 2006, when we moved the system closer to the house.

The existing modules, plus an additional six by 64 watt and 12 by 130 watt, were bolted to cyclone-proof racks, facing north at the 18$^0$ latitude angle.

*The house's main strength comes from its double curvature roof. This forms an immensely strong beam that is tied down to 600 mm of concrete by forty 100 mm x 100 mm square steel posts. Further diagonal posts are each set into 5 tonne of concrete. There are no internal walls. The frame is stressed to withstand over 230 km/h cyclonic winds. Pic: 2010 - successfulsolarbooks.com*

The modules were set up in seven paralleled banks, each of six series-connected modules, for a nominal 72 volts, and an actual 110 volts or so off-load.

The output was fed via twin dc circuit breakers via 25 $mm^2$ cable buried in 32 mm conduit to a cyclone-proof shed 25 metres away. It led from there, via a 75 amp fusible link, to an Outback Power MPPT 60 amp solar regulator to feed 16 by 230 amp hour Exide gel batteries housed in a specially built battery room accessible via an external cyclone-rated roller shutter door.

The regulator monitored incoming energy only, so a Xantrex Energy Monitor was added. Later expanded to 4 kW, the system generated a year-averaged 18 kWh/day: more than enough to run the property even in the often overcast wet season (November-April).

There was a 5.9 kVA back-up generator and 50 amp NZ-built Stanbury Engineering charger but they were only needed for a total of less than 50 hours mainly whilst moving the system to its later location.

*Outdoors shower used the ultra-clear bore water. Pic: successfulsolarbooks.com*

## Water

The house has deep, wide full length stainless steel gutters concealed between the roof and the ceiling. These run via 100 mm downpipes to two common 200 mm mains and then to a 14,700 litre holding tank, behind and below the house. This tank accepts the Kimberley's huge short-term cyclonic rainfalls. It often filled in 30 minutes.

Water was pumped from the holding tank to interconnected 100,000 litre and 25,000 litre tanks 75 metres away, via a 0.75 kW pump and 50 mm pipe. Requiring 80% of the average rainfall of 670 mm, the full 125,000 litres was invariably collected during the wet season (in 2008 inside 10 days).

Rainwater was used for all household needs including toilet flushing. There was usually 20% left over each year.

The water was pumped to the house from the holding tanks via twin (linked) 500 litre pressure tanks at 360 kPA (50 psi) and dropping to 140 kPA (20 psi) - when a 0.67 kW pump refilled the two tanks once or twice day - requiring about five minutes each time.

## Irrigation

The bore (producing crystal clear water) initially had an on-line Grundfos SQ bore pump, but this proved less than successful. We understood later, from Grundfos' Darwin office, that this pump is not recommended

*Cyclone-resistant module racks. The main structures are fabricated from 100 mm by 50 mm by 1.9 mm DuraGal steel C section, braced by 50 mm wide by 3 mm thick DuraGal steel strip. Similar 50 mm DuraGal strip reinforces the sides and ends. The racks are bolted down to 600 mm by 600 mm steel reinforced concrete footings. Pic: 2003 - successfulsolarbooks.com*

for use in the Kimberley. Our ongoing pump problems convinced us to change to a more reliable, albeit less efficient, system that provided back-up in the event of bore or bore pump woes.

The new system had a 21,000 litre tank adjacent to the bore, and a standard 0.75 kW unit bore pump. The bore pump filled the tank until cut off by a float switch. It automatically turned back on when the sooner of two conditions occurred: (a) the batteries reached float voltage or, (b) the tank level dropped below 13,600 litres. The former signal was derived via an energy monitor, the latter from a second float switch. See page 28 for details.

*Co-builder Maarit Rivers, and property runabout - a rare Haflinger 4WD. Pic: author 2008.*

A separate 1.13 kW pressure pump fed the irrigation system, swimming pool, and outside taps. This was controlled by a pressure switch that cut in at 140 kPa (20 psi) and out at 280 kPA (40 psi). A 500 litre pressure tank aided efficiency. The mainly drip-feed irrigation supplied about 3500 litres/day via five separate valve-controlled circuits.

Gate valves were used in each circuit to reduce pressure to 50 to 70 kPa (7-10 psi) required (this is necessary as the tropical sun weakens irrigation piping and clips).

## Swimming pool

The 31,000 litre pool used bore water. About 2000 litres was turned over each day by running the irrigation feed via the pool.

As can be seen on page 31, a pipe rose from just above the bottom of the pool, to about 15 mm above normal water level, and then dropped back down and into the irrigation system.

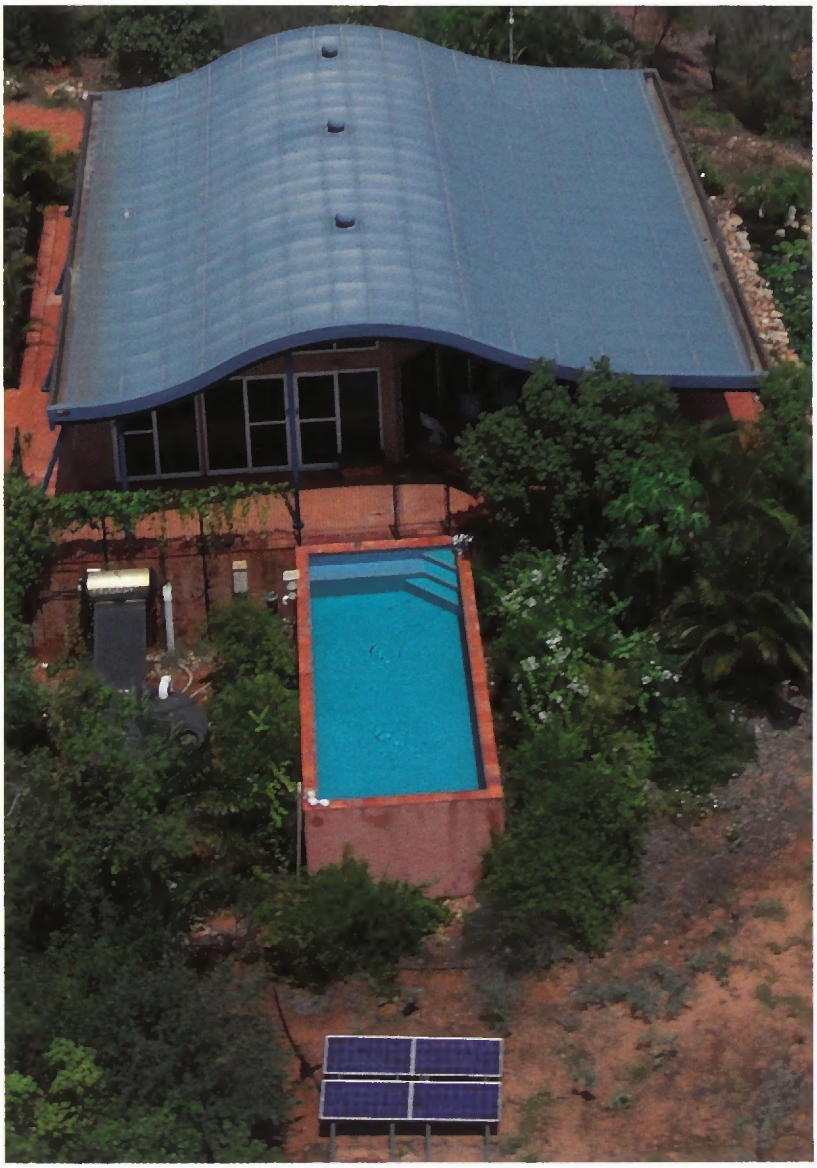
When a timer valve let in water, the level rose until it reached the horizontal section of pipe and then down four metres into the irrigation system.

The pool's 48-volt brushless dc motor's circulating pump ran 12 hours a day from four dedicated 120 watt modules.

As there was no need to circulate the pool water at night, battery storage was not required.

## Current

Our 12-year sea-change came to an end in September 2010 when, with considerable reluctance, we sold the property and relocated to a house at Church Point (35 km north of Sydney) directly overlooking Pittwater.



*The pool had its own dedicated solar modules. A family of wallabies lived nearby. Pic: 2004 - successfulsolarbooks.com.*

Whilst being an environmentally built house, previous power usage exceeded 30 kWh/day. We tracked down over 4 kWh/day in phantom loads, including a door chime's power supply that drew 960 Wh/day, and an instant boiling/freezing device that consumed over 2.0 kWh/day without water even being drawn.

The house had over seventy 35 watt halogen globes, plus walls lit up by 10 spot lights - each drawing 150 watts. Those, and all external lighting was progressively replaced by LEDs. We removed and sold (for $750) the boil/freeze unit, and replaced the door chime by a manually rung ship's bell.

We then installed a 2.4 kW solar grid-connect system, a 420 litre solar hot water heater, and a Solar Venti space heating unit (that proved less successful than hoped).

We experimented with solar time shifting using small dedicated charge/battery/inverter systems that 'time-shift' daylight generated power, to various areas overnight. In light of the major tariff changes (pages 58-61) we are currently converting day-time winter heating to be done by reverse cycle air conditioning. This will be powered by the solar array that will have its solar modules tilted to just under $60^0$.

It is possible we shall also install a permanent ac-coupled time shifting system as we will still have excess summer power.

*Solar array on roof of the author's now home in Church Point, Sydney. It faces north-east at less than latitude angle to also capture the haze reflected irradiation from Pittwater some 50 metres in front of the elevated house. The peak input from the nominally 2.4 kW system is over 18.5 kWh/day during summer. Pic: 2012 - successfulsolarbooks.com*

# Technical Terms – what they really mean

**Ac (alternating current):** A flow of electricity that alternates in polarity. Each double alternation forms one complete cycle (Hz). Alternating current's working action is like a two-person saw that is alternately pulled to and fro, cutting on both strokes. It is abbreviated as ac. (See also Dc).

**AGM (Absorbed Glass Mat):** A sealed lead-acid battery that holds the electrolyte within a fibrous silica glass mat.

**Amp:** A common abbreviation of ampere, and the unit of measurement for instantaneous electric current. See also 'current'. Amp is abbreviated as A.

**Amp hour:** This brings a time element into the above. A current of one amp that flows for one hour is thus one amp hour. It is abbreviated to Ah or A.h.

**Available capacity (battery):** The charge, in amp hours, that a battery delivers under specific conditions.

**Battery:** An assembly of cells that stores electrical energy, in the form of chemical energy, for later use.

**Cable size:** Unless otherwise defined, cable size is best taken as referring to the cross-sectional area of its copper conductor, i.e. the copper bit up the middle that carries the current.

**Charge rate (of a battery):** The rate of current flow (in amps) that restores its available capacity.

**Circuit breaker:** A switch that automatically protects against excess electric current.

**Current:** The rate of flow of electricity (akin to the rate of water flow in a pipe). It is expressed in amps.

**Current shunt (also shunt):** Used to monitor high currents remotely. Current flowing through the shunt causes a proportional voltage to be generated across it. That voltage is shown on a meter (in amps). This negates the need for the massive cabling and meter otherwise required to measure heavy currents directly.

**Conductance:** The ability of a material to conduct electricity – hence conductor.

**Cycles per second:** Now more commonly expressed as hertz (Hz), i.e. the number of times each second that alternating current completes its bi-directional movement.

**Dc (direct current):** That associated with solar modules and batteries. It is called direct current because it flows only in one direction. Its working action is akin to a band-saw. It is expressed in amps. Abbreviation is dc.

**Dc-dc converter:** Electronic device that increases or reduces direct current.

**Deep cycle:** A term for batteries that will stand deeper discharging than (say) starter batteries. The term can mislead because deep cycle batteries degrade quickly if routinely deeply discharged.

**Depth of discharge:** The percentage of capacity drawn from a battery, 40% discharge implies there is 60% remaining.

**Diode:** A device that allows electrical flow in one direction only (an electronic version of a one-way street).

**Earth:** Literally the earth (in the USA, the ground). In many countries, the neutral conductor of alternating current equipment is connected to an earthing rod that is pounded into the soil.

**Electricity:** A form of energy produced in various ways that results in a flow of electrons.

**Electron:** An elementary particle that has a negative charge. An electric current is a flow of electrons.

**Electrolyte:** A liquid or semi-liquid that carries electric current by ion movement (rather than electrons).

**Extra-low voltage:** Direct current below 120 volts ripple-free, and alternating current below 50 volts.

**Feed-in tariff (gross):** Payment made by an electricity producer (or other body) to the owner for *all* output from a grid-connect solar system, regardless of whether used within that system, or fed into the grid network.

**Feed-in tariff (net):** Payment made by an electricity producer (or other body) to the owner for the *surplus* output from a grid-connect solar system that is fed into the grid network.

**Float charge:** The current required to balance that lost by (a battery's) internal self-discharge.

**Fuse:** A heat sensitive device that melts and cuts off power to protect against excess current.

**Frequency:** The number of cycles per second by which an alternating current completes its bi-directional movement – see also 'cycles per second'. Frequency is usually expressed in Hertz – or abbreviated as Hz.

**Gassing:** The emission of hydrogen and oxygen from the electrolysis of water from a charging battery.

**Gel battery:** Sealed lead-acid battery in which the electrolyte is held within a silica gel matrix.

**Grid:** a national or local network that distributes electricity.

**Grid-connect:** Suitably configured systems that draw power from the grid, and supply power to it.

**Hydro-turbine:** A rotary device that converts the kinetic energy in a flow of water into electricity.

**Insulation:** A material that strongly resists electron flow.

**Inverter:** A unit that converts direct current to alternating current (typically to 230 volts ac).

**Irradiance:** Direct, diffuse and reflected solar irradiation that falls on a surface. Expressed in $kW/m^2$.

**ISO:** International Standards Organisation.

**Joule:** Basic ISO unit of energy and work – 1 joule/second equals 1 watt.

**Low voltage:** In Australia and New Zealand, low voltage is direct current between 120 volts and 1500 volts and alternating current between 50 volts and 1000 volts. See also 'Extra-low voltage'.

**Maximum Power Point:** The combination of voltage and current where power output peaks.

**Maximum Power Point Tracker (MPPT):** A technique that, by constantly optimising voltage and current, enables a solar regulator to operate at peak efficiency. Also known (in simpler form) as a maximiser.

**NOCT (Nominal Operating Cell Temperature):** The actual temperature of cells inside a solar module at $25^0$ C ambient is typically $47^0$-$49^0$ C. The NOCT output allows for this and other losses and is typically about 70% of claimed maximum output. NOCT data thus more closely indicates what solar modules put out in real life. It is usually disclosed on a data panel on the rear of each solar module - or buried in the small print.

**Parallel (connections):** Connecting negative to negative, and positive to positive of (say) batteries and solar modules. Doing so increases current, voltage remains the same. See also 'Series connection'.

**Peak Power Point:** That point of the voltage/current output of a solar cell or module where the product of the two results in maximum power.

**Peak Sun Hours (PSH):** The number of hours per day equivalent to the sun's irradiance at 1 $kW/m^2$.

**Phantom loads:** Many electrical devices continue to draw some current if switched off only at the device. The current drawn is called a 'phantom load'.

**Photovoltaic:** A substance capable of generating voltage from visible or other radiation.

**Power factor:** The ratio of the power (in watts) that is actually consumed in an alternating voltage circuit, to the power (in volt-amps) that is apparently being drawn from the power source.

**RCD (Residual Current Device):** A safety device that constantly checks that current flow in active and neutral leads are identical. An imbalance indicates a fault and the device cuts the power to that circuit.

**Resistance:** The opposition to flow of electrons. Handy in electric kettles, but not in the wiring to a fridge.

**Series (connection):** Linking by connecting positive to negative, (as in two 12 volt batteries to obtain 24 volts). With series connections, voltage is additive, current remains the same. See also 'Parallel (connections)'.

**Solar Constant:** The average amount of solar radiation that reaches the earth's *upper* atmosphere on a surface perpendicular to the sun's rays. It is equal to 1353 watts per square metre. The average maximum at ground level is 800-1000 watts per square metre.

**Solar noon:** The time at a specific location, where the sun reaches its highest apparent point in the sky.

**State of charge:** The amount by which a battery is charged (relative to its total capacity).

**Surge capacity:** The ability to withstand and supply a short-term overload e.g. of electric current.

**Temperature compensation:** Adjusting charging current to compensate for temperature change.

**Tilt angle:** The angle at which a solar array is set to face into the sun relative to the horizontal.

**TLC:** Three Letter Acronym.

**Varistor:** A resistor that allows current to pass if the applied voltage is excessive. Varistors are used as lightning protectors in solar cabling. They also allow high voltage static to flow to earth.

**Voltage:** The pressure that causes current to flow (akin to water pressure in a pipe). Expressed as volt, or V.

**Voltage drop:** A conductor's resistance to current flow causes a loss of voltage along that conductor. As a result there will be less volts at the load end than at the supply end. This difference is called 'voltage drop'.

**Watts:** The unit of power which is the rate at which work is done or energy transformed to do that work.

**Watt-hour (also Wh or W.h):** The unit of work or energy equal to one watt for one hour.

# References & Contacts etc.

## Useful sources of information

Alternative Technology Association: ata.org.au

Australia and New Zealand Solar Energy Society: anzses.org

Australian Greenhouse Office: greenhouse.gov.au

Bushlight Foundation (solar for Indigenous communities): bushlight.org.au

Carbon offset providers: carbonoffsetguide.com.au

Centre for Appropriate Technologies: ata.org.au

Clean Energy Council: cleanenergycouncil.org.au

Energy ratings of products: energyrating.gov.au

Geothermal Resources Council: geothermal.org

General solar grants information: cleanenergy.org.au

Research Institute for Sustainable Energy: rise.org.au

## Recommended books and publications

*Solar That Really Works!* -3rd Ed. (ISBN: 0-9578965-6-5): oriented to caravans, motorhomes and small cabins. Publisher is Caravan & Motorhome Books, PO Box 356, Church Point, NSW 2105.

*Caravan & Motorhome Electrics* - (originally *Motorhome Electrics*) (ISBN: 09578965-9-X): this book is written for a general readership, but bought globally by those technically knowledgable seeking to know about this field. Both are bought by TAFE (in Australia) and auto-electricians worldwide.

The above books are available via our websites – caravanandmotorhomebooks.com and successfulsolarbooks.com and published by Caravan & Motorhome Books, PO Box 356, Church Point, NSW 2105. Tel: 02 9997 1052. Both websites have an Articles section that is constantly updated. The books are stocked by Jaycar Electronics, Low Energy Developments, Altronics and an increasing number of retail outlets. See also http://caravanandmotorhomebooks.com/where-to-buy/ also http://www.successfulsolarbooks.com/how-to-order-our-solar-books/.

*ReNew* magazine: (quarterly): all aspects of alternative energy: renew.org.au

*Sanctuary* magazine (quarterly): sustainable houses and living etc: sanctuarymagazine.org.au

*Earth Garden,* sustainable living and alternatives: earthgarden.com.au

*Solar Living Source Book* (ISBN: 0-916571-04-1, Chelsea Green Publishing). American mega-presentation but it has a mass of (sometimes dated) information on who makes what and where.

## Relevant standards

AS 4509.1: 2009 Stand-alone power systems: Safety and Installation.

AS 4509.2: 2010 Stand-alone power systems: System Design.

AS 4086:1993 Secondary batteries for stand-alone power systems.

AS/NZS 5033:2012 Installation of stand-alone photovoltaic (PV) arrays.

AS/NZS 3000:2007 Electrical Wiring Rules - Amended in 2012.

AS 1768:2007 Lightning Protection

AS/NZS 1170.2 Wind Loads

AS4777 Grid-connections of Energy Systems via Inverters

There is also a draft version of photovoltaic array installations for the standards on grid-connection of energy systems via inverters.

## Rebates, etc.

These change constantly. The most useful source is: renewable@environment.gov.au

## References relating to electrical supply changes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ABS, Australian Bureau of Statistics (2015) Employment in Renewable Energy Activities, Australia, 2013-14, cat. no. 4631.0: abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4631.02013-14?OpenDocument

AEMC, Australian Energy Market Commission (2014) Rule Determination: National Electricity Amendment (Distribution Network Pricing Arrangements) Rule 2014, 27 November 2014: aemc.gov.au/Rule-Changes/Distribution-Network- Pricing-Arrangements/Final/AEMC-Documents/Final- determination.aspx

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Moyse, D., Alternative Technology Association (2014) Submission to ESC Draft Determination - Victorian feed-in tariff 2014, July 4, 2014: esc.vic.gov.au/getattachment/87e1b5df-37ce-45c8-9307-7134fa790822/Alternative-Technology-Association- (ATA).pdf

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Wood, T., Carter, L. and Harrison, C. (2014) *'Fair pricing for power'*, Grattan Institute: grattan.edu.au/report/fair-pricing-for- power/

Wood, T., Hunter, A., O'Toole, M., Venkataraman, P. and Carter, L., Grattan Institute (2012) *'Putting the customer back in front: How to make electricity prices cheaper:'* grattan.edu.au/report/putting-the-customer-back-in-front-how-to-make-electricity-prices-cheaper/

Hart, L., *AC versus DC coupling – Advanced energy transfer in solar systems,* ReNew 130 January-March 2015.

Reddaway, A, *Going hybrid – Adding batteries to grid-connected solar,* ReNew 132, July-Sept 2015.

Turner, L., *Knowing your renewables – Off-grid basics*, ReNew issue 128 July-September 2014.

Wood, T., Blowers, D; and Chisholm, C, *Sundown, sunrise: how Australia can finally get solar power right*, Grattan Institute: ISBN: 978-1-925015-67-6

Vica, M., *What happens when we unplug – the economics of going off-grid.* ReNew 128, July-September 2014.


(The above URLs are accessible in digital form at http://successfulsolarboooks.com/references)

This down-to-earth book shows how to make solar work reliably, consistently and economically. It explains what can realistically be run from solar: and what cannot. It covers the energy typically used (and saveable) for every aspect of a home or property, from TVs to irrigation systems. It shows how to assess the available sun year around (anywhere) and how to assess the size system you need. It covers design and installation in depth.
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